Sections of Granite and Basalt seen under polarised light.
(after Fouqué & Lévy.)

Watson & Son lith 93 Gt Charles St Birm.

J. W. Watson del et lith

(1) Quartz. (2) Orthoclase. (3) Oligoclase (4) Apatite (5) Biotite
(6) Actinolite (7) Epidote.
(8) Olivine (9) Labradorite. (10) Augite (Black) Magnetite.

MANUAL OF GEOLOGY

Theoretical and Practical

BY Maroon

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IN TWO PARTS

PART I.

PHYSICAL GEOLOGY AND PALÆONTOLOGY

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With Tables and Illustrations

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PREFACE.

From the days when Geology began to develop into an exact science, the student has been encountered by guides in the form of books, of two kinds; one promising to "lead him the sweetest and easiest way;" the other demonstrating that "of things good and beautiful, the Gods give nothing to men without great toil." The earlier writers gathered facts from too wide a field to demonstrate the steps of geological evolution. In the words of Professor Suess: "It is an exceedingly difficult task to teach a science well, which grows as rapidly as ours. The difficulty is not caused by the enormous yearly increase of new observations, because this may be overcome by patience, and by a diligent study of every good memoir. But I find that many of our best men go wrong in hanging to details, and losing sight of the grand features of science, or in proclaiming popular theories, and forgetting the painful arts of observation amidst the applause of a short-sighted crowd."[1] The difficulty of teaching has also been the difficulty of text-book writing. And among the few works which have aspired to achieve a noble ideal, probably the most honoured place must be given to the Manual of Professor John Phillips. As the nephew of William Smith, he knew the history and growth of geological ideas as well as facts; and as a public teacher was not unmindful of the aspects of geology which are of vital importance in unfolding thought and imagination for the learner. He was thus eminently fitted to state the principles of the science in their mutual dependence;

[1] Letter of 1866.

and to elucidate them with the history of British and Foreign strata. His book was in advance of the needs of the time, worthy of the University in which he taught, and no doubt the best Manual of Geology which had been written. The law of science, however, is progress. Since 1855, the date of the last edition, geology has grown in every element, has developed new departments of petrology, and become separated from physical geography; but the plan of the old book still stands, unaffected and excellent. We therefore accepted the responsibility of revising the Manual of Geology, and thus honour the memory of an eloquent teacher, whose geniality reflected the happy influence of nature, who if not a brilliant discoverer had verified much of what was known, and was a sound geologist of balanced philosophical habit.

In this volume I have preserved every page of the original work that was in any way valuable. But the changes necessary to bring the science of the last generation into harmony with current knowledge and thought, have been more serious than were anticipated when the revision began. I have omitted much, have added more, and modified always; while from exigencies of space I have elected to omit certain subjects, and not to develop others to the length to which they might profitably be followed. Yet with this literary regeneration, the spirit of the old book has been preserved, and it has been revivified with the spirit of the newer geology which is unfolding.

In endeavouring to sustain that part of the title-page which describes the Manual as *theoretical*, I have drawn to some extent upon theoretical views enunciated in my lectures during the ten years from 1860 to 1870, for which Professor Sedgwick, F.R.S., deputed to me the practical teaching of Physical Geology and Palæontology in the University of Cambridge; not altogether foregoing a hope that days of requisite leisure may yet come, in which the facts dependent upon those views may be elaborated to their legitimate ends.

The work will be found *practical* too; for it aims through-

out, by indicating localities where phenomena may be seen, at enabling every one to verify, and study in nature, the statements and ideas which are herein set forth. Only in this way can knowledge become valuable, and independence of thought be fostered.

This elementary study over, I commend the reader to the second volume, in which Mr. Etheridge tells the History of the Strata, with a wealth of fact which has hitherto had no parallel.

H. G. SEELEY.

THE VINE, SEVENOAKS,
September 15th, 1884.

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Knowledge should be practical from the first. The student may form gradually a small collection of specimens, and those will often be most instructive which are collected by himself; but in cases where collection of specimens is not possible, it may be useful to mention that—

Minerals and Rock Specimens may be obtained from Mr. Gregory of Charlotte Street, Fitzroy Square.

Collections of Slices of Minerals, Rocks, and Fossils for the Microscope are supplied by Messrs. How & Co., of Farringdon Street.

Mr. Cattell of Leighton Road, Kentish Town, is skilful in slicing rocks and fossils for microscopic study.

PHYSICAL GEOLOGY.

CHAPTER I.

DEFINITION AND ORIGIN OF THE SCIENCE.

Objects and Scope of Geology.—The term "science" is understood to express, not only the information or facts collected, and the laws founded on this knowledge, but also the ultimate objects and whole field of research. Thus the science of Geology embraces that department of the philosophy of nature, which investigates the formation and structure of the earth and its system of development, including the building up of rocks, succession of life, production of minerals, &c., and all the changes which the earth has undergone. Geology, in fact, treats of the earth's history and its constitution as a planet, subject to physical laws that have produced changes in the materials of the earth's crust, and have modified the succession and distribution of life in different regions from age to age.

It is in conformity with this ordinary language that we shall endeavour to define geology. None of the sciences of observation has made more remarkable progress toward successful generalisation than this, yet the prospect of further discovery is so much richer than the retrospect, and the ability employed in the research is so much more skilled now, that we can hardly offer too expanded an expression for the ultimate aims of geology.

Geology then, in its fullest extent, is that science which undertakes to investigate the ancient natural history of the earth; to determine by observation what phenomena of living beings or inorganic matter were formerly manifested on or within the globe, in what order and under what conditions; to employ the comparative data, which are furnished by investigating the present operations of nature as a means for characterising and measuring the successive revolutions which the earth has undergone before it arrived at its present state; and thus, finally, to furnish a complete historical view of the conditions which have regulated, and still regulate, its system of mechanical, physical, chemical, and vital phenomena.

From the terms of this definition we may at once understand why,

in former times, the most able men erred in their attempts to elucidate the history of our globe; for, while physical geography was imperfectly known, before commerce and the knowledge of languages had made us acquainted with the productions and traditions of every nation and clime, before the birth of most branches of physical science, it was impossible to accumulate the numerous and exact observations from which alone geology takes its origin. And since the general truths of geology are made apparent only by the application of the known laws of modern nature, it is evident that, before the discovery and establishment of those laws, the wisest of the old philosophers had nothing to substitute for enlightened theory but arbitrary hypothesis and fanciful conjecture. These are the reasons why the ancient doctrines concerning the world are almost without exception bewildered with the impossible problem of the creation of matter, and buried in a chaos of subtle inventions.

The early writers of Babylon, Phœnicia, Chaldæa, Egypt, and China, were occupied, almost absolutely, with the cosmogony or origin of the world, and neglected its physical history.

What Herodotus says regarding the sediments deposited by the Nile in the valley of Egypt, and carried out to sea; of the time (10,000 or 20,000 years) which he estimates as sufficient for the Nile, if diverted into the Erythræan Sea, to fill up that long gulf;[1] and of the shells found on the hilly borders of Egypt which testify to its former submersion beneath the sea, may, however, be quoted with approbation as a fair specimen of ancient observation and inference.[2]

Origin of Inductive Geology.—Four different classes of phenomena conducted men of observation to a partial acquaintance with the stratification of the crust of the earth.

1. The effects of disturbance in countries shaken by earthquakes and marked by periodical volcanic excitement—as Asia Minor, Italy, &c.

2. The arrangement of the various strata in England and elsewhere.

3. The appearances of regular structure in the mines of England, Germany, Sweden, &c.

4. The remains of plants and animals which are found entombed almost everywhere, where the water-formed or stratified rocks are examined.

1. Of the first class of observers, the most distinguished in early times is Strabo, who gives an interesting account of the Katakekaumene (burnt district), in the valley of the Hermus, in Asia Minor—a district which remained almost unvisited till Mr. Hamilton renewed our acquaintance with its remarkable features, so similar to those of Auvergne. Etna has engaged the attention of observers from the time of the Greek poets and philosophers down to the period of Daubeny, Scrope, and Lyell, all of whom have endeavoured to trace the

[1] Her. ii. 11: *ἐγὼ μὲν ἔλπομαί γε καὶ μυρίων ἐντὸς χωσθῆναι ἄν*——

[2] Her. ii. 12: *ἰδών τε τὴν Αἴγυπτον προκειμένην τῆς ἐχομένης γῆς, κογχύλιά τε φαινόμενα ἐπὶ τοῖσι οὔρεσι.* The shells were, perhaps, truly "fossil," and belonged to the rocks in the hilly ground.

source of its fires, their origin and decay. And the phenomena connected with eruptions, which fatally stimulated the curiosity of the elder Pliny, have trained up in modern times philosophic men like Steno[1] and Lazzaro Moro,[2] Sartorius von Waltershausen,[3] Palmieri,[4] Abich,[5] Robert Mallet,[6] who not only perceived succession of time in the deposition of the strata, but great physical changes—displacements of land and sea—affecting large areas of country. It is in this school that we find the germs of our modern theories of elevation and depression of land, whether by the sudden violence of volcanic heat, or gradual effort depending on a general change of dimensions due to temperature of the globe—this being the Leibnitzian theory.[7]

2. **Agriculture.**—The early advancement of agriculture in a country so populous, and of so diversified an aspect as England, necessarily produced a very intimate knowledge of different soils; and as these depend on the nature of the structure and composition of the underlying rocks which range through the country in regular courses, it is not surprising that maps of the soil should have been early proposed and prepared by agriculturists. Dr. Lister, residing in Yorkshire, where the limits of soil are very well defined, was the first to propose to the Royal Society, in 1683, a map of the soils of England.

3. **Mining.**—Miners in every period must have been generally acquainted with the order of succession of the rocks through which they seek for coal and other minerals; and in tracts consisting of alternating coal-seams, limestones, sandstones, and shales, the range and extent of the different strata must always have been familiar to the workmen, although perhaps in an empirical manner.

There must, therefore, always have been a Mineralogical School of Geology in every country in which rich subterranean treasures attracted the attention of mankind.

Agricola embodied the floating information of the miners of Saxony as early as 1546 (*De Naturâ Fossilium*); he was followed by Cordas, Gesner, Kentmann, Fabricius, Encelius, "not unworthy of praise," as we are told by Baier (*Oryctographia Norica*, 1708). Sweden, equally celebrated for its mines, produced, between 1730 and 1762, five complete systems of mineralogy, including the methods of Linnæus, Wallerius, Swab, and Cronstedt.

In 1750 Tylas, a Swede, and in 1756 Lehmann, a German, broke through the fetters of a mere mineralogical method, and by proving a regular order of superposition among stratified rocks, opened the way for the sagacious generalisations of Werner, and the cautious inductions of Saussure.

Werner.—A peculiar set of opinions concerning the formation of the earth has been honoured by the title of the Wernerian theory; and the pupils of Werner, who had found proof of the truth of his

[1] De Solido Intra Solidum, &c., 1669.
[2] De Crostacei, &c., 1740.
[3] Atlas de Ætna, 1845–61.
[4] On Vesuvius.
[5] Vues Illustratives de Phénomènes Géologiques Observés, &c, 1837.
[6] Earthquake Catalogue, 1858; Ueber Vulkanische Kraft, 1875.
[7] Protogæa, &c., 1680.

practical rules and inferences, may be readily pardoned for the determination which they manifested to uphold Werner's hypothetical notions. But if we wish to ascertain the real value of the benefits which the researches of Werner have conferred upon geology, we must forget his theory, and view only the data which he collected for its foundation.

Werner was educated amidst the mines, and in the society of the most eminent mineralogists of Saxony; their experience and their opinions became his own, and doubtless swayed and directed the energies of his mind. To judge from his own works, and from the course which his pupils so long pursued, the principal point of view under which Werner contemplated the rocks and metallic veins of Germany, was the relative period of their production. Lehmann had, indeed, taken the same course, and already distinguished Primary and Secondary rocks, the former (*a*) existing in mountain chains, mostly stratified, at high angles, and devoid of organic remains, the latter (*b*) disposed more horizontally, and stored with the remains of life.

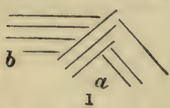


Fig. 1.

But Werner, with characteristic tact and boldness, applied this method of investigation to every case, and took it as the basis of his classification of rocks.

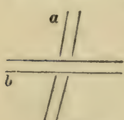


Fig. 2.

Basis of his System.—"When two veins (*a b*) cross, and one of them (*b*) cuts through the other (*a*), the one which is divided (*a*) is the more ancient."

Among stratified rocks superimposed on one another, the lower members of the series, those which lie nearest the centre of the earth, were deposited first, and the relative antiquity of the different strata is exactly in the order of their position. Thus *c* is the oldest rock of the series *c*, *d*, *e*, *f*, *g*.

By this manner of proceeding in the instance of the Harz Mountains, Werner was enabled to frame a system or classification of rocks in the order of their respective position as far as could then be ascertained, and consequently in the order of their consecutive formation. Thus the Brocken Mountain was described by Werner and his followers as a central cone of granite, upon which on all sides round were laid various other rocks in a certain and constant order of succession; as granite, clay-slate, limestone, greywacke and greywacke-slate, old red sandstone, limestones, gypsums, sandstones, and limestones; the upper and newer strata having their outgoing or terminal edges lower and lower continually.

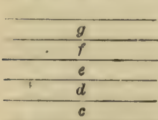


Fig. 3.

He presumed that the order of succession among these rocks in Germany would be found to prevail in all parts of the world, and thus announced a grand principle in the construction of the earth which was destined to have a most beneficial effect on geological theory and observation. For, on the one hand, it dissipated the chaotic dreams of those who maintained that the whole crust of the earth was to be

viewed as a mass of sediment from the waters of "the deluge"; and on the other, exhibited the most important subject of inquiry respecting the constitution of the earth, and fixed a precise method of investigating it.

That Werner's classification is partly erroneous in principle, and in all respects incomplete, and inadequate to the rigour of modern investigation, is apparent at a first glance, but it obviously contains the essence of rightly planned arrangements, viz., a determined reference to the relative antiquity of the deposit. Werner is, therefore, entitled to the distinguished praise of clearly announcing and striving earnestly to establish one of the most important general laws yet ascertained respecting the structure of the earth. He proved that in a particular district its stratified rocks are laid one on another in a certain order of succession, and affirmed that the same, or a very similar order, prevailed over large parts of the earth's surface.

Michell.—One of the ablest of the natural philosophers of England during the middle of the eighteenth century, who, for a short time, filled the Woodwardian chair of geology at Cambridge, and afterwards resided in Yorkshire, had certainly made himself acquainted with the series of English strata, especially in the northern counties, and had even gone so far as to discover some of the most important general relations between the geological structure and the physical features of the globe, defining with a masterly hand the mutual dependence of mountain ranges and lines of stratified rocks.

In frequent journeys between Cambridge and Yorkshire, mostly performed on horseback, he composed a useful section of the strata between the chalk hills of Bedfordshire and the coal strata of Nottinghamshire, but never printed an account of his discoveries. What he stated concerning the succession of strata in Derbyshire and other parts, was chiefly derived from the miners and colliers, who, certainly, for a hundred years before the dawn of sound geology, knew perfectly the almost invariable sequence of strata in their own districts.

4. **Inductive Geology principally founded on the Organic Remains.**—The great fact upon which, in modern times, geological inquiries have hinged, the occurrence of marine animals far from the sea and deep in the solid earth, was so far understood by the ancients, that they had ascertained the general agreement of fossil and recent marine shells.

But the sixteenth century was wholly wasted among the naturalists of Italy, France, England, and Germany in the ridiculous dispute whether fossil shells were genuine marine exuviæ, or mere *lusus naturæ* produced by a plastic power of fermenting fatty earth? and the inquiry assumed a more difficult character from the addition of the question, whether, if they were genuine petrifactions, they were all deposited by the Noachian deluge?

In examining both of these points the Italian philosophers were by far the most conspicuous, and it is difficult to understand how the sound conclusion of Fracastorio (1517), Scilla (1670),[1]

[1] La Vana Speculazione Disingannata, Napoli, 1670.

Ramazzini,[1] and Vallisneri,[2] could fail to become the universal creed of geology. Palissy, the philosophic potter of France, published, in 1557,[3] from his own experience, the conclusion that fossil shells and other "figured stones" were the genuine exuviæ of ancient marine animals.

Progress of Palæontology in England.—In England, the great interest which belonged to the thousands of fossil plants and animals, was fully understood by Plot, Llwyd, Ray, Lister, Woodward, and Moreton; who by their rich collections, and publications, as well as resolute though unsuccessful efforts to deduce the causes which had thus buried and preserved imperishable in the earth organic remains of a former period, undoubtedly kindled that ardent spirit of inquiry respecting the structure of the earth, for which the English philosophers of the seventeenth century were so honourably distinguished.

Nevertheless, the progress of geology in England was retarded by the fettered condition of other sciences, and by a peculiarly unhappy conjunction of truth and fiction. The correct view of the original nature of "formed stones, or petrifactions," was coupled by Woodward and his numerous followers with the assertion, that all the strata superimposed on one another in the crust of the earth, with all their included myriads of fossil animals and plants, were deposited by one general flood, "the deluge!"

One great merit, however, strikingly characterises the early English school of geology, even in its greatest aberrations,—a thorough conviction that the organic remains entombed in the earth were the surest evidence of the revolutions which it had undergone.

Lister.—Through the research and learning of this industrious and distinguished man, England was filled with collections of fossils, which were compared with native and exotic living species, and almost every naturalist of note from the time of Lister has contributed something to the stock of information respecting them. Lister was free from theoretical prejudice, had the merit of perceiving and of recording in a single instance the principle of mutual dependence between the strata and their organic remains, which afterwards, generalised and promulgated by Smith, became the most important instrument of investigation which has ever been presented to geology.

Speaking of a small species of belemnite (*B. Listeri*), which is figured in his *Historia Animalium Angliæ*, he says it is found in all the cliffs as you ascend the wolds, for above a hundred miles in compass, at Speeton, Londesbro', and Caistor, but always in a red, ferruginous earth. This correct and remarkable result is a striking example of the possibility of even holding in the hands a brilliant discovery, without knowing its value, or taking any steps to ascertain its importance.

[1] De Font. Mutin. Scat.; b. 1633, d. 1714. His observations are quoted by Vallisneri, Lazzaro Moro, Linnæus, &c.

[2] De Corp. Mar., and other works; b. 1661, d. 1730.

[3] Palissy's work was first printed at Lyons in 1557. The edition of 1580 usually referred to, was the third.

Smith.—A century later, the perception of the same truth, in several instances near Bath, and the demonstration of its applicability to the whole Secondary series of the strata of England, enabled Mr. William Smith, by his own unaided efforts, to establish the geology of England on a basis from which it can never be shaken. He made an accurate classification of the stratified rocks in the order of their relative antiquity, accompanied by catalogues of their organic contents, and a map of their ranges and distribution on the surface of the island in conformity with the order of succession of the rocks in the interior.

To study the laws of nature according to the principles developed by Mr. Smith, to ascertain by the order of succession of deposits and by organic remains, what were the contemporaneous effects of the natural agents employed in the formation of the earth's structure in all parts of the world, is the first great problem of modern geology. By the aid of zoological and botanical researches we determine the relative antiquity of every species of fossil plant and animal, and assign the relative period during which its existence was continued. The fossils called *Orthoceratites*, *Producta*, Trilobita, and many Crinoidea, belong to the older and lower rocks; certain species of Echini, *Ammonites*, *Belemnites*, and other shells, mark the Oolitic strata; while others belong to the Chalk; and a different series of plants, corals, shells, and remains of vertebrate animals lie above the chalk, to those found below. Such inferences, drawn from observations in Europe, have been found constant in America; and this powerful instrument of research thus placed in the hands of the observer, having been wielded with the caution requisite in questions of analogy, the principles disclosed by Mr. Smith's researches near Bath and elsewhere, and illustrated by Cuvier's philosophical description of the environs of Paris, are found to be universally applicable; for the distant slopes of the Himalaya and Andes, and the shores of Australia and Greenland, are united in the mind of the geologist who contemplates the evidences of their coeval stratification.

Hypotheses.—We here close our short account of the growth of geology into a science. The paths of observation, along which alone the foundations of the science are to be sought, were hard and difficult; those hypotheses which they displaced were easy and inviting. The globular figure of our planet, the inequalities of its surface, and the occurrence of marine shells in mountains far from the sea, have been thought sufficient data for rashness and speculation to construct detailed theories of the earth, to determine the constitution and condition of its centre, and to describe, as if men had actually beheld them, the successive revolutions which the world had undergone.

These hypotheses were most numerous and discordant during the period when positive geology had made the least progress; with the advancement of knowledge they diminished in number and improved in consistency; and at the present moment, though every theory has lost its power of fettering the mind, there is a tacit but almost universal agreement in those fundamental principles of structure, and circumstances of origin of phenomena, by which alone every passing

theory must be judged, and to which also all good observations and sound inductions must be referred. To develop these principles in a settled order, to illustrate by their aid the geological structure of the British isles, and to connect and correlate the geology of Britain with that of Europe and other parts of the globe, and thus rise by a legitimate process to those comprehensive inferences which the subject admits of, is the aim of the following pages.

CHAPTER II.

MODERN VIEWS OF THE EARTH'S DENSITY, SHAPE, STRUCTURE, AND ORIGIN.

The earth's density, size, and shape, are all closely connected with each other. The earth is five and a half times as heavy as a globe of water of the same size would be. It is twice as heavy as a similar globe of granite, half the weight of a like globe of lead, and about a fourth as dense as though it were made of solid gold. This density of the earth is also called its specific gravity. But specific gravity is the weight of a substance in air divided by the difference between its weight in air and weight in water, thus:—

$$\frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water.}} = \text{specific gravity.}$$

In the case of the earth, the specific gravity is inferred by comparison, not determined by experiment. There are several ways in which the density of the earth has been estimated. The most important of these are known as the Schiehallion method, the Pendulum method, and the method of Cavendish. The Schiehallion method, used by Maskelyne in 1742, is essentially this: If a line with a weight attached to it is suspended, it points towards the centre of the earth. Such a plummet was so placed as to be attracted by the somewhat isolated mountain in Perthshire, named Schiehallion. The size and density of the mountain being known from measurement and by weighing samples of the rocks, the amount was calculated by which the line ought to be attracted towards it by the mass of the mountain. And since the line was not drawn towards the mountain nearly so much as it would have been if the earth had been throughout of the same density as the mountain, it follows that the earth as a whole must be much denser; and, in fact, is found by this evidence to be twice as dense as that mountain, or, in other words, has the density indicated by the number 5½. This experiment has been repeated at Edinburgh and at Mont Cenis, yielding nearly the same results, though in both these cases the density appeared to be slightly less than at Schiehallion. The Pendulum method, invented by Sir G. B. Airy in 1854, consisted in observing the difference between the movements of a pendulum at the bottom of the Harton colliery, near South Shields, and on the earth's surface.

If the earth had throughout the same density as the rocks at its surface, the pendulum would beat slower at the bottom of a mine than at the top; because the attraction of the earth is then that of a globe lessened in radius by the distance which you descend towards its centre; and as the force of gravity thus becomes diminished with the decrease of the mass, the pendulum swings more slowly. But at the bottom of the mine the pendulum actually goes much faster than at the top, showing that the interior of the earth is formed of materials much more dense than the surface rocks. But the density found in this way being $6\frac{1}{2}$, is so much greater than that found by other methods that it is not usually regarded as quite so reliable, and the experiment has not been repeated. The method of Cavendish, who used a torsion balance, is of a different character. It has been repeated twice, and gives the earth a density of $5\frac{1}{2}$. This being the mean of the various observations, is believed to be as near the true density as possible. It however by no means follows that the interior of the earth consists of substances which have a high density at its surface, since the compression due to gravity alone would greatly condense the materials forming the earth, and give to the interior a high density, even though it consisted throughout of such minerals as form the surface rocks. But the effects of this pressure in condensing the interior of the globe would be far more considerable than they are, were they not resisted within by some general antagonist force, such as the expansive power of heat, or an extraordinary want of compressibility among the particular substances operated on. It may be useful to compare with the specific gravity of the earth itself the specific gravities of a few of its constituent minerals and metals as shown in this table :—

	Sp. gravity.		Sp. gravity.
Sulphur	2.0	Iron	7.5
Dolomite	2.8	Copper	8.5
Calcspar	2.5	Lead	11.0
Felspar	2.5	Mercury	13.0
Quartz	2.6	Platinum	19.0
Mica	3.0	Gold	20.0

From such a list it is evident that the heavier metals can only form a small portion of the interior of the earth. But if the high density of the earth were supposed to be connected with an original fusion which allowed heavy substances to gravitate towards the centre, then it must be remembered that our only knowledge of the existence of such substances in the earth at all is from their occurrence at the surface, where on such a theory they ought not to be found. It is, therefore, improbable that the earth's density is a result of the arrangement of different mineral constituents in successive layers like the coats of an onion, with the density decreasing towards the surface; and density probably gives no insight into the interior construction of the earth.

The Figure of the Earth, as it is commonly named, is such as would be ultimately attained by a rotating body, no matter what its original form may have been. If the earth had ever been a sphere, then the wearing and transporting power of water would gradually cut down the

polar protuberances, and transport the materials towards the equator, owing to the action of centrifugal force. At present the polar diameter of the earth is nearly 26½ miles less than its equatorial diameter. There is no reason, however, for supposing that the earth was ever more nearly spherical than now, while, on the contrary, the shape may not improbably have been approximating towards the sphere from a remote period. The flattening of the earth's poles which gives it the orange-like form called an oblate spheroid, is so small in amount that the eye is quite unable to detect the flattening upon any accurate model of a globe that can be made. This figure may result from many causes. Seeing that the excess of length of the equatorial over the polar radius amounts to but little more than the difference between the greatest mountain height and greatest ocean depth, that fact is conclusive proof that the earth is sufficiently elastic to owe its flattened form to rotation alone, especially when it is remembered that the centrifugal force or tendency of things to fly from the earth is at the equator $\frac{1}{289}$th of the force of gravity which draws all things towards the earth's centre of attraction. Hence the shape of the earth may be due entirely to deformation, or alteration from the spherical form, consequent upon rotation, so that altered position of the earth's axis would explain emergence and submersion of land. If any part of the interior of the earth should be fluid, it is possible that the way in which centrifugal force might influence the tendency of internal heated matter to fly towards the equatorial region, might appreciably affect the expansion of the rocks in the equatorial plane, and thus account for a difference between polar and equatorial diameters. Sir William Thomson has stated that if the earth were wholly composed of glass, its mean expansion for every degree increase of Fahrenheit temperature between 30° and 212° would be 1 part in 69,660; if it were of iron the expansion in the same limits would be 1 part in 50,760; while if the earth were all copper, the expansion for each degree would be 1 part in 34,920. If, for the sake of illustration, we assume the mean temperature of the earth at the equator to be 80°, and suppose no increase of temperature to take place towards its centre, and further suppose the earth to consist of copper, then there would be an increase of the earth's diameter in the equatorial region of many miles, owing to the expansion of the metal; and if no corresponding or any less elongation took place towards the poles, there would be a considerable equatorial bulge due to this cause. It is therefore probable that the earth's internal heat has to be considered as a factor which has influenced its form.

The Earth's Solidity inferred from the Stability of its Figure.— The difference between the polar and equatorial diameters being $\frac{1}{300}$th of the earth's diameter, gives the earth's surface a curve which deviates from the circle towards an ellipse by about 1 in 300. And this fact coupled with some remarkable discoveries in the relative motions of the moon and earth made by Professors Adams and Delaunay in 1859 and 1866, led Professor Sir William Thomson to speculate from the earth's form upon the length of time for which the earth may

possibly have existed. The argument is as follows: The moon at the end of a century gets to be between five and six seconds of time in advance of her natural place in the heavens with regard to the earth. It was suggested that this difference *probably* resulted from the extent to which the earth's movement is retarded by the friction against it of tidal waters. And when this idea was worked out it was found that the tides were competent to produce a retardation of the earth four times as great as the difference between the motion of the earth and the moon. Hence it followed, if the data for the calculation are correct, that 10,000,000 years ago the earth must have been rotating $\frac{1}{7}$th faster than it rotates now, and therefore that the centrifugal force must have been to the centrifugal force now in the proportion of 64 to 49. So that if the earth had consolidated at that remote period, the ellipticity of its upper layers would have been a curve of 1 in 230, instead of a curve of nearly 1 in 300, which the earth actually has now. Therefore, allowing for all possible errors, Sir William Thomson concludes that the consolidation of the earth from a molten state (if it were ever fluid) must have taken place at some period considerably more recent than 1,000,000,000 years ago; and since that far-off period when the earth began to consolidate, consolidation has progressed till it is probable that at its centre no part of the earth is now fluid. The evidence on which this conclusion rests is remarkably forcible, for if the earth's interior were to any large extent fluid, our planet would behave as a fluid body, and be drawn out of shape by the attracting forces external to it, just as the sun and moon draw the ocean towards them in tidal movement, and tides would not exist. On the contrary, however, the earth is extremely rigid, probably as rigid as though formed throughout of solid cold steel, and would appear only to yield a few inches to the attracting powers which produce tides, so that there can be no ground for assuming a fluid interior, when it must be so far removed from the surface, even if existing, as to be inappreciable by any effects manifested at the surface.[1]

Evidence of the Globular Form of the Earth.—The figure of the earth has been determined more accurately by actual measurement; but its globular form has been long demonstrated by experience and observation of the following facts:—

First, during an eclipse of the moon the shadow of the earth is cast upon the moon so as to exhibit under all circumstances a nearly circular outline; and since this outline is sometimes cast by different aspects of the earth, the demonstration by this means of the earth's globular form is perfect. The Egyptians, Babylonians, and early Greeks all were aware of this evidence of the earth's shape. Secondly, navigators such as Ferdinando Magellan in 1519, Sir Francis Drake in 1577, Sir Thomas Cavendish in 1586, and many others, sailing constantly to the west have returned to the point in Europe from which they started, and thus by sailing round the world have demonstrated the earth's spherical form. Thirdly, by ascending increasing heights above a plain in any part of the world, the distance to which the eye

[1] Thomson and Tait's "Natural Philosophy."

can recognise the geographical features of the country is steadily increased, and the circular horizon becomes larger; and this can only be explained on the hypothesis that the earth is a sphere. Because if a number of tangents be drawn to a circle at equal distances on each side of a point, and the lines are prolonged so as to meet each other in pairs above that point, then it will be evident that only on a spheroid can the horizon be a circle, which is enlarged proportionately as the eye is elevated above its surface. Fourthly, ships at sea gradually sink farther and farther below the horizon as their distance from the shore increases, until even the tops of the masts disappear. This is regarded as proof of the earth's spherical form because, first, it is exactly analogous to the way in which a man disappears from view by walking over ground which rises in a rounded form; and, secondly, because the object which has disappeared can be seen again if we climb a cliff a sufficient height above the sea. Fifthly, if three rods of equal length are set up on a straight canal free from locks at equal distances from each other, so that the top of the most distant post can be seen through a telescope fixed to the top of the post at the other end of the canal, then the top of the middle post will be seen to rise considerably above the straight line between the two end points; and this can only be because the surface of the water is not level, but has a spherical curve, and therefore goes to prove that the earth's surface is spherical.

There was no suspicion of the polar flattening of the earth, so far as is known, till the time of Sir Isaac Newton. In the year 1671, Richer, at Cayenne in South America, found that the pendulum of the clock which he had brought from Europe was no longer of the right length to keep time, vibrating more slowly the nearer it was moved to the equator, so that the clock lost $2\frac{1}{2}$ minutes a day. It thus became known experimentally that the force of gravity diminished towards the equator, because the rapidity of the pendulum swing is in proportion to the intensity of the earth's attraction. And so soon as one of the 360 degrees into which a circle passing through the centre of the earth is divided, had been accurately measured, it became possible to determine the size of the earth and to calculate the figure which the earth ought to assume in consequence of its rotation. This rotation diminishes the force of gravity at the equator by $\frac{1}{289}$th; and the total force of gravity is now known to be $\frac{1}{194}$th greater at the pole than at the equator. It was hence calculated that the earth must be flattened towards the poles by an amount nearly equal to that afterwards found by measurement. The exact amount of flattening has been determined by finding the curve of the meridians in different latitudes; and the degree of a meridian has been repeatedly measured, and is known to increase in length from 362,644 feet at the equator to 366,489 feet at the pole. A degree is always $\frac{1}{360}$th of a circle, and as the circle becomes larger so the degree obviously becomes longer. The lengthening of the degree then, towards the pole, is evidence that the earth's outline there becomes a part of a larger circle, or in other words, it becomes more flattened and more of an

ellipse, because the larger a circle is the more nearly any part of its circumference approaches to a straight line. This polar compression or flattening makes the polar diameter of the earth almost 26½ miles shorter than it would be if the earth were a sphere. According to the most recent estimate, the measurement of the earth from pole to pole is 7899.2 miles. But the equatorial circumference may also be slightly elliptical, though the compression is estimated to amount to less than 2 miles. It is well known that large masses of land rise above the general level to a height of a mile or two, and it is quite possible that the equatorial irregularity of outline, if it really exists, is a consequence of the contractions of the earth's crust which have changed the form of the globe by elevating the great continents.

The Earth's Orbit as Influencing the Temperature of its Surface.—The earth's orbit is an ellipse; its distance from the sun varies from 89,860,000 miles to 92,950,000 miles. The earth is nearest the sun in our winter about the beginning of January, when it is in the position called perihelion; its distance then is about three millions of miles less than in summer, when it is in the position called aphelion. The amount of heat received from the sun varies inversely as the square of the earth's distance from it, so that at first sight the summer at our antipodes would seem to be warmer than our own summer; but when the earth is nearest to the sun its rate of motion is most rapid, as may be seen from the circumstance that there are fewer days in winter than in summer, and this rapidity of motion compensates for the reduced distance, and the earth receives about the same amount of heat in each of the seasons. A more remarkable circumstance about the earth's orbit is the fact that the ellipse itself rotates, going forward 1° in 308 years. And this throws the positions of the equinoctial points backward, so that the seasons change their times with regard to the earth's surface, and of course our summer comes round eventually to happen when the earth is nearest to the sun. It is also calculated that owing to the attractions of the planets the eccentricity of the earth's orbit varies both by the ellipse becoming longer and shorter; this change would probably greatly influence climate, by modifying the amount of heat that the earth would receive from the sun; because the more elongated the form of the orbit, the less is the distance of the earth from the sun in perihelion and the greater its distance in aphelion; though Professor Dove found that the mean temperature of the whole of the earth's surface in June is much higher than in December, owing to the land being chiefly in the Northern Hemisphere. When the eccentricity of the earth's orbit is greatest, this part of the world may come to be eight and a half millions of miles farther from the sun than it is now in winter; and though at present winter is nearly eight days shorter than summer, it then might be thirty-six days longer than it is now. It is certain that from this cause important changes of climate must occur every 10,492 years. At the last of these periods, when the earth was nearest the sun in summer and farthest off in winter, the difference of temperature due to that position was calculated by Sir John Her-

schel to probably amount to 23° F. A maximum eccentricity of the earth's orbit is calculated to have been reached 210,000 years ago, and a still greater eccentricity 850,000 years ago, when the winter would have been forty-four days longer than now, and the mean temperature of the coldest month is stated at $-7°$ and that of the hottest month at 126°. Mr. Croll has appealed to these principles as evidence of a rotation of climates on the earth in past time, and especially in explanation of the general phenomena of cold and glaciation to which the northern regions of America and Europe were subjected during the time which has been called the glacial period. The hypothesis on astronomical grounds is speculative, but not impossible, and deserves attention.[1]

Modern Speculations concerning the Origin of the Earth.—The sun and many of the distant fixed stars are formed of mineral substances, similar to those which make up the earth's surface. This conclusion has been arrived at by studies with the spectroscope. This knowledge being the foundation for all sound ideas concerning the internal state of the earth, it is necessary to explain the evidence on which it rests. When a ray of light enters a dark room through a small slit in the shutter, and falls upon a triangular prism of glass held near the slit, the light which passes through the glass is bent and divided into the colours red, orange, yellow, green, blue, indigo, and violet; and this band like a rainbow is named the solar spectrum. These colours are divided up into narrow strips by an immense number of parallel delicate dark lines. Thousands of these lines have been accurately drawn, and they are found to be always in the same positions, some in each of the colours. They were first studied by the Bavarian philosopher Fraunhofer, and are hence called Fraunhofer's lines. These lines indicate the existence of many substances which are burning in the sun's atmosphere. And since the light which those substances give is less brilliant than that of the blazing atmosphere in which they burn, it follows that the rays from them come to the earth relatively dark, and appear as dark lines in the spectrum. The true meaning of Fraunhofer's lines was discovered by experiments with the spectroscope upon minerals and metals which form the earth's crust. The spectroscope, invented by Professors Kirchoff and Bunsen of Heidelberg, is merely a telescope with a triangular prism of glass at the end to break up the light into a spectrum. And when a substance is burned in a flame like that of a Bunsen's burner, and the light from it falls on the prism, the spectrum becomes more or less altered, and instead of a perfect spectrum certain bright lines are seen, which are different for every metal or substance examined. Thus if a piece of clean platinum wire, which will not burn, be touched with the finger and held in the flame, all the colours of the spectrum disappear except a brilliant yellow line in the part of the spectrum where the yellow colour should have been. This yellow streak is caused by burning sodium, which passed through the skin in the form of sodium chloride or common salt. The bright line thus

[1] Croll, "Climate and Time."

formed is in exactly the same place as the dark line in the yellow part of the solar spectrum, which Fraunhofer indicated by the letter D. Hence the conclusion is arrived at, that the light produced by sodium burning in the sun is the cause of the appearance of this line in the solar spectrum. Similarly, potassium gives a dull spectrum with all the colours, but has a brilliant red line in the extreme end of the red portion, which corresponds with the dark line in that position called by Fraunhofer A; and there is a second line for this substance at the extreme end of the violet part of the spectrum. Iron when burnt in the electric light yields about seventy bright lines. On this kind of evidence about eighteen common metals, metalloids, and gases have been identified as contributing by their incandescent vapours to produce the sun's atmosphere. Among these substances are sodium, calcium, magnesium, iron, nickel, copper, zinc, cobalt, manganese, aluminium, barium, chromium, strontium, cadmium, titanium, hydrogen, and oxygen. Hereafter many other elements may be found.[1]

When a metal is burned on the earth, it enters into combinations with gases and becomes an earthy or mineral substance. Hence, it is probable that the combustion now going on in the sun, which illuminates the whole solar system, will form in that star rock-substances not unlike those which constitute the earth; and we are led to infer that at some far-distant time the earth itself may have been incandescent at its surface, as the sun now is, and that the chemical combinations of elements which form its rocks can thus be accounted for as products of combustion.

It has also been shown that the vast outer enveloping portion of the sun's atmosphere is formed of the gas hydrogen in a burning state. There is every reason to believe that hydrogen burns there as on the earth, by combining with oxygen gas. The product of this combustion is vapour, which must ultimately condense into water when the heat is less, and, dissolving soluble salts, accumulate eventually in depressions on the sun's surface so as to form oceans and seas. It is at least probable that the earth has passed through a phase of this kind, and that all the water on its surface was produced just as water may now be produced artificially, by the combustion of hydrogen in oxygen gas. This conclusion is the more likely since the earth's atmosphere is merely a mechanical mixture of oxygen and nitrogen, as though it were the incombustible residue of gases left after the combustible materials on its surface had burnt themselves out. The other planets are apparently more or less like the earth in possessing atmospheres and seas; and Mars so far resembles the earth as to display white snow-capped poles; and both that planet and Jupiter exhibit changing shapes of clouds, which in Mars frequently assume similar outlines over large portions of its surface, as though land and water were grouped into large masses. If the moon has neither atmosphere nor oceans, it may well be that the atmosphere of gases was small while it was undergoing combustion, and that they were entirely combined with the burning elements.

The phenomena produced by combustion must, at the smallest

[1] Roscoe, "Spectrum Analysis."

estimate, extend far deeper than man can ever penetrate. Some other facts bear upon the origin of the earth itself.

Observations with the spectroscope prove that many of the fixed stars are suns, more or less like the central luminary of our solar system. Thus in the light from a star Aldebaran, Mr. Huggins found the lines which indicate hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury. And many of the fixed stars, like Sirius, give the light which is produced by incandescent hydrogen; and there are very few of the fixed stars in which hydrogen has not been detected. Thus the matter of the universe appears to be as universal as the laws of force, by which its existence is manifested and controlled. It is certain that each of these vast burning worlds is slowly increasing in size by combining the gases of its atmosphere with the superficial substances which burn; and that eventually they must all burn out when the atmosphere is exhausted, or when the supply of combustible material comes to an end. And this consideration leads up to what has been called the "nebular hypothesis;" because, if we suppose the sun, for instance, always to have been about as large as it is now, it is difficult to conceive how chemical combinations like those now occurring on its surface, could have taken place throughout its entire mass from the centre outwards, because the gases which support combustion are usually less dense than the vapours which combustion would produce. And since these vapours when condensed would so accumulate as to form a protecting envelope, it has sometimes and naturally been supposed that the central mass of the sun and of the planets may be less oxidised or earthy than the part which is near the surface. The nebular hypothesis supposes that before the stars existed, the materials of which they consist were diffused in the heavens in a state of vapour. The nebulæ in the firmament had been observed to fill enormous areas in space, and to give a dull kind of light which long ago suggested that they might be gaseous matter in process of being condensed into worlds. And Sir William Herschel speculated that if they condensed by their own gravity, they would assume more or less spheroidal forms and be denser towards the centre. Then assuming that local centres of condensation would come into existence and gradually absorb the nebulous matter, the nebulæ would become resolved into clusters of stars.[1] There may be some truth in this conception, though the nebulæ are now known to be dense masses of stars, and in no respect nebulous. And if the masses of matter already condensed became drawn into contact with each other by force of gravity, sufficient heat might be developed by the concussion to melt or vaporise the whole mass. Such a heated mass might then by rapid rotation throw off rings which would cool, break, and condense into masses like planets, and if the condensation took place with sufficient force, the planet might in its turn throw off a ring which in due course would condense into a satellite. This is speculation, it is true; but it is speculation supported by a number of astronomical facts; and it is mentioned now because it helps us to

[1] Herschel's "Astronomy."

comprehend, though it may not altogether explain, some views concerning the nature of the earth's internal heat, its form, and its relations to the solar system. Even if the hypothesis is true, there is great probability that the final condensation of each globe was gradual; and that after the main fiery mass of our planet was formed, smaller cooled masses fell into it and bombarded the earth, and furnished new fuel for combustion and added to the earth's size, just as the falling-in of such masses appears to furnish the fuel which keeps the sun burning. This probability is great because meteorites from time to time still fall to the earth, and in past time may well have fallen in far greater numbers. Sir William Thomson speaks of Temple's Comet of 1866 as consisting of minute planets, "of which a few thousands or millions fall towards the earth annually about the 14th of November, when we cross their track." These minute planets called meteorites vary in weight from a few ounces to a few tons. They have been repeatedly seen to fall, and sometimes explode when near the earth. They have been found on the surface or buried a few feet in the earth, in all parts of the world from one pole to the other.

Inferences from Meteorites.—A large number of the specimens in the British Museum are from America; a few have been found in our own islands, many in various parts of Europe, and no small number in India. Some of the largest are from Australia and Greenland. These masses are either crystalline compounds of native iron with a moderate percentage of nickel, or else consist of such minerals as form volcanic rocks, often with a little metal scattered in them. A few meteorites contain bituminous substances such as upon the earth are only produced under the influence of plant or animal life; but it is impossible to say how those chemical compounds originated in meteorites. In the Arctic regions minute spherical particles of iron are sometimes brought down from the air in snow, as though the earth occasionally entered clouds of meteoric dust. A like cause must account for the red rain which fell at Blankenburg in 1819, and owed its colour to cobalt chloride; and in some soils, as at Lahisberg in Austria, nickel and cobalt occur at the surface, though there are no neighbouring mineral veins or rocks from which such elements could be derived. Among the substances which compose meteorites are the minerals which are named Labradorite, anorthite, orthoclase, augite, hypersthene, bronzite, enstatite, olivine, Hauyne, graphite, chromite, magnetic pyrites, all of which may be found in volcanic rocks of a more or less basaltic character; while in addition there are iron, nickel, cobalt, tin, copper, lead, manganese, sulphur, phosphorus, chlorine, nitrogen, oxygen, and hydrogen.[1] We know of no masses of metal on the earth which correspond in composition or mode of occurrence with these meteoric masses, unless some meteoric iron found in Greenland Basalt is to be regarded as originally terrestrial in origin. The meteorites, however, which now fall belong to an altogether different

[1] Flight, History of Meteorites, "Geological Magazine," 1875.

orbit from the earth, immensely more elongated, and therefore cannot be considered to have built up the mass of the earth; but they demonstrate how such materials might, by the action of gravity, become drawn together into a planet. And if the mineral materials which have fallen to the earth are a fair sample of those which move in the heavens, we obtain from them a useful idea as to what the interior of a globe would be like, formed by such materials being attracted towards each other. If the force which brought the smaller masses together were sufficiently great to develop heat enough to convert them into vapour or to melt them when their motion was stopped, then no doubt the metals, being heavy, would find their way towards the centre, and the rocky substances being lighter would remain at the surface. By help of such considerations, we obtain some clue to the origin of the earth, which, although vague, has an inductive foundation. The meteorites, which Dr. Hahn, however, believes to contain corals, sponges, encrinites, and other fossils, cannot be accepted as evidence that life exists, or has existed, in the distant heavenly bodies.[1]

[1] Die Meteorite (Choudrite) und ihre Organismen. Dr. Otto Hahn Tübingen, 1880.

CHAPTER III.

THE CHIEF MINERALS WHICH FORM THE EARTH.

It has already been seen that minerals may be now in process of formation in the sun, and the fixed stars; that they form meteorites, and compose the earth's surface. It will be a sufficient definition of a mineral to say that it is the natural condition in which the substances that form rocks exist in the earth. Chemists have classified the constituents of the earth into elementary bodies which no analysis has yet been able to further subdivide. Some of these elements, more or less pure, occasionally constitute minerals, such as sulphur, carbon, copper, silver, gold. But more frequently minerals consist of several elementary bodies chemically combined, and then each compound thus made up, is met with usually in a series of geometrical crystalline shapes, and each has a distinctive hardness, colour, mode of cleavage or crystalline splitting, and other peculiarities, by which it may be more or less easily distinguished from other minerals. Thus the mineral galena, a well-known bluish-grey metallic-looking ore of lead, consists of a chemical compound of lead and sulphur, which crystallises in some modification of the cube or octahedron, and readily cleaves parallel to the faces of the cube.

The abundant chemical elements in the earth are remarkably few, and may be enumerated as oxygen, silicon, aluminium, calcium, sodium, potassium, iron, manganese, magnesium, lithium, chromium, carbon, barium, sulphur, chlorine, nitrogen, fluorine, and hydrogen, which is usually present in combination with oxygen forming water. These elements, variously combined with each other, constitute the minerals which compose rocks, and though occasionally minute quantities of other elements occur in rocks, yet not more than half of those named will usually be found. The mineral substances constituting aqueous or water-formed rocks, are massive and rarely crystallised, though various crystallised minerals occur in them; and as the minerals of water-formed rocks are usually different in character and appearance from the same substances when found in igneous rocks, it may be convenient to enumerate them separately in tabular form. They include :—

Mineral Substances which Constitute the Aqueous Rocks.

NAME.	COMPOSITION.	MODE OF OCCURRENCE.
Quartz	Oxide of silicon; when crystallised is in six-sided prisms terminated by six-sided pyramids.	In grains forming sand and sandstones, in concretions forming flint and chert in limestone, more rarely in crystals filling cavities in rocks and concretions, and massive in quartz veins and quartz rock.
Calcite	Carbonate of lime, also called calcium carbonate; when crystallised is in scalenohedrons or three-faced pyramids, rhombohedrons or some form in the Rhombohedral system.	Usually amorphous, forming limestones, and occasionally crystalline as in the skeletons of echinoderms, especially encrinite limestones of the Carboniferous age. It also occurs combined with clay in concretions called septaria.
Clay	It is not, properly speaking, a mineral, but a rock; when pure it is identical in composition with decomposed felspar, chiefly silicate of alumina	In beds often made up of thin layers. Slate is a hardened and altered condition of clay. Shale is clay hardened by pressure and infiltration of mineral substances.
Gypsum	Hydrated sulphate of lime	Chiefly in clays in masses called alabaster, and in transparent crystals called selenite.
Dolomite	Carbonate of magnesia combined with carbonate of lime	Forms the magnesian limestone in the Permian rocks as between Nottingham and Sunderland, &c., in this country; and other rocks.
Rock Salt	Chloride of sodium	Occurs in beds chiefly in the upper part of the Trias in this country, as at Droitwich, Nantwich, Shirleywich, and near Carrickfergus in Ireland. But isolated cubic crystals are found in other formations like the Purbeck and coal.
Iron Pyrites	Sulphide of iron .	Cubic crystals common in many old slates. Iron pyrites or Marcasite in all clays and many limestones. In the chalk these masses are radiated and popularly called thunderbolts.
Phosphatite	An amorphous variety of the mineral apatite, which is phosphate of lime, otherwise called tribasic calcic phosphate	Occurs in beds of irregular concretionary nodules in the Red Crag, Coralline Crag, Upper Greensand, Gault, Upper Neocomian, Rhætic, and Bala beds.
Glauconite	In green grains, a hydrous silicate of iron, alumina, magnesia, soda, and potash	Colours Bracklesham beds, Thanet sands, Upper Greensand, Lower Greensand, &c.

Among the other minerals which form beds of rock are coal, the various oxides of iron, and carbonate of iron; which we shall describe in another place. And among minerals found in the strata are alum, barytes, &c. For technical descriptions of these species reference may be made to a treatise on mineralogy such as Dana's, or Rutley's, or Phillips' Mineralogy by Brooke and Miller. And in any case, the best knowledge of them will be obtained by examining the specimens in some public collection, such as the British Museum or Museum of Practical Geology, or the Museums of our Universities.

The abundant minerals which form igneous rocks are rather more numerous, but comprise chiefly the felspars, augites, hornblendes, micas, talcs, quartz, olivine, garnets, zeolites, and a few others. The more interesting general facts relating to the species of these groups which bear upon rock structure may be thrown into a tabular form for easy reference. Of quartz nothing further need now be said.

The Minerals Forming Igneous Rocks.

The Family of Felspars.

Felspars are the most abundant minerals in igneous rocks. They can be just scratched with a knife, being softer than quartz, harder than apatite, and much harder than carbonate of lime. The colour is often milky-white, sometimes bright red owing to the presence of oxide of iron, and occasionally grey or black, or even green. All felspars consist chemically of silicates of alumina combined with some other silicate, which is usually silicate of potash, or soda, or lime, or some combination of lime and soda; and according to variations in chemical composition, the different varieties or species of felspar are identified and named. With these chemical differences are associated differences of crystalline form. When a typical felspar contains potash, it crystallises in prisms in what is called the oblique or monoclinic system, and is recognised by fracturing at right angles to the side of the prism; but when the crystal contains soda or lime it crystallises in the doubly oblique or triclinic system, and the cleavage is then at an oblique angle. For most purposes it is sufficient to identify these two groups known as orthoclase and plagioclase, which can almost always be recognised even in microscopic examples by the different ways in which they affect light, when examined in thin slices, under the microscope, with the aid of the polariscope. There are, however, at least six species of felspar properly so called, which are named orthoclase, oligoclase, albite, labradorite, anorthite, and andesine; the nearly allied minerals which may replace the felspars in igneous rocks are nepheline, leucite, sodalite, haüyne, and noseau (Cotta's "Rocks Classified and Described;" Zirkel's "Lehrbuch der Petrographie.")

NAME.	COMPOSITION.	ROCKS IN WHICH FOUND.
Orthoclase	Double silicate of alumina and potash, with a little soda	Granite, syenite, porphyry. Is green from containing copper in some of the rocks of South America and Colorado.
Sanidine	A grey and glassy variety of orthoclase, usually with a little lime and magnesia	Trachytes, phonolites, pitchstones, obsidian.
Adularia	A nearly transparent variety of orthoclase with a little lime	Granite of St. Gothard.
Albite	Double silicate of alumina and soda. Usually associated with orthoclase	Trachyte of Pantellaria, miascite of Miask in Siberia, granite of the Muorne Mountains, and in various granites, greenstones, and gneiss, though not as a chief constituent.
Oligoclase	Double silicate of alumina and soda, in which the soda is partly replaced by lime and potash	In granite of many places in Sweden and Scotland, in gneiss near Freiberg, in syenite, the Verde - Antico porphyry of the Morea, the trachytes of Teneriffe, and in diabase and diorite.
Labradorite	Double silicate of alumina and a compound of soda and lime. Usually with a little iron. Dissolves in hot hydrochloric acid	In the gabbro of Skye, in all basalts, dolerites, hypersthenite, older lavas of Etna, &c.
Anorthite	Double silicate of alumina and lime, in which the lime is partly replaced by small quantities of soda, potash, or magnesia. Usually a little iron. Dissolves in hydrochloric acid	Old lavas of Monte Somma, Thjorsa in Iceland, napoleonite of Corsica, diorite of Harzburg, syenite of Carlingford.
Andesine	A grey, green, or red double silicate of alumina, and a compound of soda and lime, usually with some potash and a little magnesia.	Occur in gneiss in Scotland, in the Andes combined with hornblende forming andesite, also in syenite of the Vosges. It resembles oligoclase. In basalt and dolerite, in mias-
Nepheline	A white or coloured double silicate of alumina, and a compound of soda and potash. Dissolves in hydrochloric acid	In basalt and dolerite, in maiscite and zirconsyenite ; in dolerite it occurs in short thick hexagonal columns ; at Vesuvius and near Rome in lavas, in phonolite as in the Wolf Rock on the Cornish coast.
Leucite	Ash-grey colour, in 24-faced trapezohedrons, but belongs to the tetragonal system. Is a double silicate of alumina and potash. Dissolves in hydrochloric acid	Unknown in the older rocks. Monte Somma lavas of Vesuvius. trachyte between Andernach and Laach, dolerite of the Kaiserstuhl in Baden. At Bohmisch-Wiesenthal in the Erzgebirge leucite crystals are changed into orthoclase.

The Family of Augites and Hornblendes.

Augite and hornblende are usually dark-green or black minerals which belong to the monoclinic crystalline system, and are commonly a little more easily scratched than the felspars with which they always occur. There are distinct crystalline forms and cleavages for hornblende and augite; but when some varieties of hornblende are melted, they assume, on cooling, the crystalline form of augite. Hence the conclusion has not unnaturally been drawn that they are essentially one mineral which assumes the form of hornblende on cooling slowly under great pressure, and that of augite when cooling in lava streams; and this view is supported by the fact that the *hornblende* is chiefly found in syenite and completely crystalline rocks, while *augite* abounds in basalts and those rocks which have cooled at the surface. But though conditions of cooling may have some influence on the development of these minerals, their formation is probably more dependent upon the chemical composition of the rock matter in which they occur, since hornblende is associated with the felspars which are rich in silica, and rocks which contain quartz, while augite is met with in association with felspars which contain less silica, and rocks from which quartz is absent. Occasionally they occur together as in trachytes of Etna, and they have been found artificially formed in slags. Chemically there is no great difference between these minerals beyond the fact that hornblende contains more alumina and magnesia, and more iron than augite, while augite contains more lime; in the pale-coloured varieties of both minerals alumina is almost absent, and the quantity of iron is greatly reduced. The chief varieties of the augite or pyroxene group are augite, hypersthene, diallage, bronzite; the pale-coloured varieties are named diopside, sahlite, and malacolite; the chief varieties of amphibole or hornblende are tremolite, actinolite, asbestus, and hornblende.

NAME.	COMPOSITION.	ROCKS IN WHICH FOUND.
Augite	Dark green or black variety. Silica, lime, magnesia, protoxide of iron and alumina. Angle of cleavage planes, 87° 5′	Basalt and dolerite, diabase and modern lavas. The pale varieties are chiefly found in altered limestones.
Hypersthene	Greenish black, distinguished by cleavage, very tough. Differs from augite in containing much less lime, hardly any alumina, and much more iron; as hard as felspar	In the gabbro of Skye, Penig in Saxony, and in the island of St. Paul on the Labrador coast. Crystals in rhombic system.

NAME.	COMPOSITION.	ROCKS IN WHICH FOUND.
Diallage	Brownish green or brassy brown; as hard as fluor spar, being much softer than augite. Contains little alumina, a little water, but otherwise is like augite, has a peculiar cleavage	Occurs in gabbros of Cornwall, is associated with hornblende in the euphotide of Harzburg Forest in the Harz, and occurs in gneiss in the Guadarrama Mountains in Spain.
Bronzite	Reddish-brown or bronzy; harder than diallage. Contains little or no alumina and lime, but large quantities of silica and magnesia. Crystals in rhombic forms	Found in serpentine at the Lizard, the Bacher Mountain in Lower Styria. Enstatite is a similar but paler mineral found in lherzolite near Lake Lherz in the Pyrenees, and in some gabbros.
Hornblende	Greenish black. The alumina, magnesia, lime, and protoxide of iron are more nearly equal than in augite, and average 14 or 15 per cent. each. Crystals columnar, angle of cleavage planes at intersection, 124° 30′	The pale-green varieties, tremolite and actinolite, are found in dolomite and altered limestone; common hornblende in diorite, syenite, hornblende gneiss, hornblende slate, phonolite, trachyte. Uralite appears to be augite partly transmuted into hornblende.

The Family of Micas and Talcs.

The talcs and micas include many species which usually agree in dividing into thin laminæ which are sometimes more or less transparent. The talcs are softer than the micas, may be bent, but will not spontaneously bend back again, give a more or less greasy sensation when touched, and are hydrous silicates of magnesia where part of the magnesia may be replaced with iron, and are not acted on by acids. The micas are usually in rhombic or hexagonal plates, are both flexible and elastic, give a clean sensation when touched, are double silicates, usually of alumina, magnesia, potash, and iron, and some species are soluble in sulphuric acid. Talcs are often deposited from water as pseudomorphs, in place of other magnesian minerals which originally formed part of the rock; but they cannot be correctly described as hydrated micas because micas contain alumina, but may be formed in rocks which were previously infiltrated with magnesian silicates derived from decomposed mica, hornblende, augite, and olivine.

NAME.	COMPOSITION.	ROCKS IN WHICH FOUND.
Talc	White, or greenish six-sided plates. Hydrous silicate of magnesia, with some protoxide of iron, and occasionally a little alumina. Insoluble in acids	In talc slate, talc-schist, in the protogine of the Alps, in protogine gneiss; when compact and amorphous is called steatite or potstone; crystals in the Zillerthal of the Tyrol, at St. Gothard, and about Salzburg.

NAME.	COMPOSITION.	ROCKS IN WHICH FOUND.
Chlorite	Dark olive green. Hydrous silicate of magnesia and alumina, with 12 per cent. of water. Dissolves in hot sulphuric acid	In chlorite slate, protogine, protogine gneiss, diabase, corresponding to mica as a rock constituent, closely related to soapstone, found in serpentine at the Lizard.
Muscovite or Potash-mica	White or brown or black. Silicate of alumina with 10 per cent. of potash, and rarely more than 5 per cent. of iron oxides, with a little water	Granite, gneiss, mica-schist, some lavas of Vesuvius; has been found in slags, and has been formed in clayey sandstone walls of iron furnaces.
Lepidolite or Lithia-mica	Red or violet. Composition similar to muscovite, but with lithia, hydrofluoric acid, and protoxide of manganese	In granite in Cornwall, in gneiss, and greisen.
Phlogopite	Brown, or reddish brown. Silicate of alumina, magnesia, potash, sometimes with fluorine and a little iron	Chiefly in metamorphic limestone, as in the Vosges; also in serpentine.
Biotite or Magnesian-mica	Usually dark green, brown, or black. Silicate of magnesia, alumina, potash, and oxide of iron, with some water, dissolves in hot sulphuric acid	In granite gneiss, trachyte, basalt, miascite, in lavas of Vesuvius. Many other micas are met with.

The Family of Garnets.

The garnets are a group of silicates of variable composition. The typical garnets have on this account been grouped under six varieties, as lime garnet, which is a double silicate of lime and alumina; magnesia garnet, which is a silicate of magnesia, iron, and alumina; iron garnet (or common garnet), which is a silicate of protoxide of iron and alumina; manganese garnet, which is a silicate of manganese, alumina, and iron; iron-lime garnet, which is a silicate of iron and lime with a little alumina and manganese; and lastly lime-chrome garnet, which is emerald green, and is a silicate of lime and chrome with a little alumina and iron. These, however, are mostly of rare occurrence in igneous rocks, and it will be convenient to assume that the common almandine garnet is the kind usually met with. The Vesuvian mineral idocrase is closely allied to the garnets, in being a silicate of lime, alumina, iron, usually with a little magnesia. Here also may be placed, though in no near association, tourmaline, sphene, and zircon. Garnets often occur embedded in talc and mica, and they may be regarded as most closely allied to that group of minerals.

NAME.	COMPOSITION.	ROCKS IN WHICH FOUND.
Garnet	Usually in rhombic dodecahedrons, red or brownish. A silicate of iron and alumina, but in some rocks containing magnesia	In eklogite, which is a compound of green diallage and garnet; in garnet rock, a compound of garnet and hornblende; occurs in mica-schist; also in granite, granulite, trachyte, perlite, and chlorite-schist.
Idocrase	Brown or green. Silicate of lime and alumina, with a little iron, manganese, and magnesia	In old lavas of Vesuvius; serpentine in Piedmont; has been found in slags of furnaces. Is not an important rock constituent.
Olivine	Green or brown; crystals in prismatic system; harder than felspar, equals quartz; dissolves in sulphuric acid. Consists of silica, magnesia, and protoxide of iron. The silica always less than the magnesia. Only a trace of alumina; no lime. When transparent called chrysolite.	In many basalts, as in the Eifel, in lavas of Monte Somma, in hypersthenite at Elfdalen in Sweden, talc-schist at Katherinenburg, in Lherzolite. Found in slags of iron furnaces. The rock in New Zealand called dunite consists of olivine.
Tourmaline	Usually black. A silicate of alumina and magnesia, with much boracic acid and oxide of iron, and a little soda, lime, and fluorine. This mineral is also called schorl	In luxullianite, granite, mica-schist; not found in volcanic rocks.
Sphene	Green, brown, or black. Silicate of lime and titanium	In granite, syenite, zirconsyenite, phonolite, trachytic rocks of Laach, and in mica-schist.
Zircon	Red or brownish. Silicate of zirconia, with usually a little iron, and occasionally a little lime	In several Scotch granites, in zirconsyenite, in basaltic lavas at Unkel on the Rhine.

The Family of Zeolites.

The zeolites are essentially felspars, which have been dissolved by water slowly percolating through rocks in which those minerals occur, and then have been redeposited in chemical combination with water, in cavities, in volcanic and crystalline rocks. They are all silicates of alumina, and several zeolites in addition contain lime, often with a little soda or potash; two others contain soda only, and one has a large percentage of sulphate of baryta. These minerals are most abundant in the vesicular basaltic lavas, but are also found in gneiss, syenite, and granite, phonolite, and lavas of Vesuvius, &c. Occasionally they form a large percentage of the rock, and furnish an instructive illus-

tration of the extent to which a rock may become altered by infiltration. It is zeolitic substances dissolved out of the basalt and re-deposited in the chalk of Antrim and Argyleshire which have imparted a flinty hardness to that rock in those localities. The following table includes some of the more interesting and important zeolites.

NAME.	COMPOSITION.	LOCALITIES WHERE FOUND.
Apophylite	A red, yellow, or whitish silicate of lime and potash, with 16 per cent. of water	Generally in cavities in amygdaloidal rocks, chiefly in Iceland and the Faroe Islands. In Tertiary limestone at Puy de la Piquette in Auvergne, near basalt.
Prehnite	Usually green. Silicate of lime and alumina, with a little iron and water	In cavities in basalt in Mull, Skye, Salisbury Crags, Dumbarton; and in granite at Botallack, near Land's End.
Thomsonite	White. Silicate of alumina and lime, with a little soda and 13 per cent. of water	In cavities of basalt at Kilpatrick, in Scotland; in lavas of Vesuvius; and in phonolite at Daubitz, in Bohemia.
Chabasite	White or reddish. Silicate of alumina and lime, with a little potash and 20 per cent. of water	In cavities in basalt at the Giant's Causeway, in Skye and Mull; and in phonolite.
Stilbite	White or yellowish. Silicate of alumina and lime, with 1 per cent. of soda and 17 per cent. of water	In cavities in basalt in Skye and Arran; and in granite, gneiss, and schistose rocks in fissures.
Laumonite	White. Silicate of alumina and lime, with 15 per cent. of water. Similar in composition to stilbite, but while that mineral crystallises in the prismatic system this occurs in the oblique system	In cavities of basalt in Dumbartonshire, and fissures in syenite at Dresden.
Heulandite	White or reddish. Silicate of alumina and lime, with 15 per cent. of water. Oblique system, but form of crystals different to laumonite, and unlike that species does not fall to powder on exposure to air	In basalt in Skye, at Campsie in Dumbarton; also in fissures in gneiss and slates.
Natrolite	White or reddish. Silicate of alumina and soda, with 10 per cent. water. Prismatic system	In basalt of Giant's Causeway, Hebrides, Rhine, &c.

NAME.	COMPOSITION.	LOCALITIES WHERE FOUND.
Analcime	Transparent or white. In 24-faced trapezohedrons. Silicate of alumina and soda, with 8 per cent. of water	In cavities of basalt and other amygdaloidal rocks at the Giant's Causeway; in the inner Hebrides; at Dumbarton, &c. In the Cyclades two-thirds of a dolerite has been changed into analcime.
Harmatome	White. Silicate of alumina and baryta, with 15 per cent. of water. Prismatic system. Usually in twin crystals, having a section like a cross	In amygdaloids at Oberstein, and in veins at Strontian in Argyleshire.

Professor Daubrée notices that not only do many of these zeolites occur in the same mass of rock, but that several occur together in the same cavity. There is every reason to believe that they owe their existence to the infiltration of ordinary water, because they have been found formed in the brickwork of several old Roman baths, as at Plombières in the Vosges, where the warm water had contained alkaline substances. The nature of the rock in which it is deposited appears to exercise some influence on the kind of zeolite formed, because the species in the mortar are different to those which occur in the bricks.

It may, perhaps, be imagined that innumerable mineral combinations are derived from the sixty-six primary chemical elements. But, as many of them are excessively rare, as the remainder combine only upon certain principles, the number of mineral species really determined is, in fact, not large, perhaps hardly exceeding five hundred. Nor is the geologist often called upon to make himself acquainted with all even of this moderate number. Unless his labours are devoted to the detailed phenomena of volcanic productions or of mineral veins, he will seldom have occasion to observe more than one-tenth of the number. The reason of this is that a large portion consists of rare and local species; and that, in combining to form rocks, the others are associated in families, and united into specific compounds without much permutation. In consequence, there is really less difficulty than might be expected in recognising and discriminating the rocks. To class and to describe them in a true natural order is difficult, to compare and to know them according to their mode of occurrence is easy, and should form part of the practical education of every geologist. The student should lose no time in obtaining slices of the chief rock-forming minerals, and must study them under the microscope with and without polarised light, if he would learn to discriminate the varieties of igneous rocks which they combine to form.

CHAPTER IV.

THE NATURE AND ORIGIN OF CRYSTALLINE AND IGNEOUS ROCKS.

THE newest water-formed rocks are similar in appearance to deposits which are now being deposited; but the older strata have often undergone changes which have obliterated some of their original features which were due to deposition, and have imparted characters which sometimes make it difficult or impossible to discover from observation that they were ever deposited in water at all. These changes are partly the consequence of the slow infiltration of water, which dissolves certain mineral constituents from one place or one rock, and deposits them again elsewhere, sometimes as crystalline minerals, but almost always in different mineral combinations; and when a rock is thus altered by the action of water, it may be said to be transformed. Other changes of a more varied and important character result from the action of pressure, when rocks are forced by folding to occupy less space. And when from this cause the original distinction between minor layers of rock disappears, and is replaced by new planes of division, and when the original mineral character of the rock disappears to give rise to a crystalline texture, and to minerals which are never found in the strata, the rocks are said to be metamorphosed. Afterwards it may be seen that these changes go so far, that lavas and granites appear to be formed out of sands and mud by the action of the heat to which pressure gives rise.

All the older Primary rocks of this country, and in other countries the newer rocks of all geological ages, have been more or less metamorphosed; clays are thus changed into slates, sandy clays into schists, certain sandstones into quartzites, and ordinary limestones into crystalline or statuary marble. When limestone is thus altered, its texture becomes amorphous or granular from the small size of the calcite crystals of which it consists; all traces of fossils disappear, frequently crystals of garnets, augite, or other minerals form; and there may be irregular films of colour, or a greyish tinge, in place of the varied or diffused colour which the rock originally possessed.

Carbonate of lime being easily soluble in heated water, a comparatively low temperature may have been sufficient to bring about these changes. An example of such a limestone in this country is seen in

the Laurentian gneiss rocks of Loch Maree in Ross, and the structure also appears wherever intrusive rocks come in contact with limestones; but the most familiar example is furnished by the Carara marble of Italy, which is probably of Carboniferous age. When sand becomes converted into quartzite, the grains of sand are more or less obliterated and blended together, as grains of sago might blend when cooked. The fracture of the rock, when the sand was fine, often resembles that of horn, hence these altered rocks are often called hornstones, but exposure to the weather usually develops on the surface a laminated structure. Here the temperature may not have been very high, since heated water has considerable power of dissolving silica, and all rocks contain more or less water, the temperature of which may be raised by pressure. Schists are rocks which consist chiefly of fine layers of crystalline quartz, arranged in short irregular parallel films, which are separated by films of some other mineral. Thus mica schist consists of quartz and mica; talc schist is quartz and talc; chlorite schist is quartz and chlorite; hornblende schist is quartz and hornblende. There are a few other schistose rocks, the most important being gneiss, which is made up of the same minerals as granite, quartz, felspar,

Fig. 4.—Mode of Occurrence of Schists in Scotland.

and mica, only the minerals are arranged in parallel layers. All these rocks contain various other minerals in small quantities, but schists especially abound in garnets. The arrangement of the minerals in parallel layers was named by Mr. Darwin *foliation*. These rocks were originally all fine sandstones and sandy clays; and under the influence and action of heat, pressure, and the water contained in the rock, the chemical substances have re-

Fig. 5.—Contorted Schist.

combined into the minerals already mentioned, being arranged in layers, which do not usually correspond with the layers in which the rock was deposited. The schistose rocks are always crumpled and contorted, and commonly occur on the flanks of the older mountain ranges.

Slates were clays, often more or less sandy and micaceous, which

have undergone enormous compression. Often they occupy only a third or even a tenth of their original horizontal space, as is shown by the distortion of the fossils they contain, and sometimes by the folding of hard sandstone layers which could not yield in the same way to the pressure. This compression alters the rock so that it no longer absorbs water freely or decomposes into mud. And while the original planes of deposition are still well marked by changes in the colour of the layers, the rock no longer splits into the strata or laminæ of which it was composed, but has acquired the property of dividing into much more regular and sometimes exceedingly thin films by division planes which cross the rocks in different quarries at every possible angle to the original stratification. This property, to which we owe the slates of commerce, was named by Professor Sedgwick cleavage. This rock cleavage is quite distinct from the cleavage of minerals, for that always depends upon the crystalline form of the mineral, and is parallel to one or more of the faces of the particular crystal system to which the mineral belongs. Thus, what is named the cubic system includes besides the cube many other figures, such as an eight-sided double pyramid called an octahedron, a twelve-sided figure named a dodecahedron, &c.; and though the mineral called fluor-spar usually crystallises in cubes, its eight corners cleave off and convert the cube into the octahedron. But rock cleavage is a mechanical property which is due to rearrangement of the rock particles and crystals by pressure. This has been proved experimentally by Mr. Sorby and Professor Tyndall, who have produced cleavage experimentally by pressure in clay, wax, and other substances. Professor Ramsay has observed that cleavage is only produced in contorted rocks when they are subject to some weight of rock from above as well as lateral pressure; since when near the surface the rocks yield and fracture, and the particles are not forced to rearrange themselves at right angles to the direction of the compressing force.

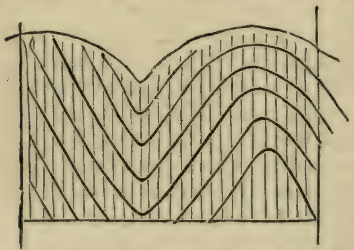


Fig. 6.—Vertical Cleavage in Folded Strata.

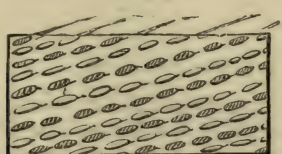


Fig. 7.—Clay Splitting Obliquely.

Fig. 8.—Same Rock converted into Slate Splitting Vertically.

The production of cleavage may perhaps be better understood from this diagram. First, we suppose the clay to be unaltered,

and to show the actual particles of which it consists here drawn greatly magnified and apart from each other; and secondly (fig. 8), we suppose the same mass of clay to have been compressed from one end, and to have yielded somewhat above. Here all the particles are seen to have shifted their positions, and to be extended at right angles to the pressure. Formerly the rock would split in the direction in which the particles were deposited, now it splits in the new direction into which the particles have crystallised. In this country slates occur throughout the Cambrian, in the Silurian, and in the Devonian rocks; and are found in Cornwall, Devon, and West Somerset, in Wales, the Lake Country, Scotland, and Ireland; but the best known slates are from the Lower Cambrian, at Penrhyn, Llanberis, and Ffestiniog. In other countries slates occur, of all geological ages. They almost always form mountain-masses with well-defined and peculiar contours.

Mr. Darwin first drew attention to the way in which the rocks showing cleavage lie parallel to those showing foliation, and drew the conclusion that foliation is only an intense form of cleavage; or is due to the same cause when the forces producing it are more powerful. There are some intermediate kinds of rocks; and Professor Sedgwick found slates[1] with the cleavage planes sometimes coated over with chlorite and semi-crystalline matter, which not only defines these planes, but extends in parallel flakes through the whole mass of the rock. And when it was found that the granite masses which often form the central bosses or axes, as they are called, of mountain chains, are parallel to the overlying metamorphic rock, it began to be suspected that granite also might be a product of metamorphism; especially as it consists of the same minerals as gneiss, and only differs in having them mixed confusedly together, instead of being arranged in parallel layers. Moreover, there are many intermediate varieties of rock; and granite in large masses often shows an approach to a banded structure, owing to the mode in which its minerals are arranged. It will readily be understood that if the constituents of gneiss have arranged themselves in

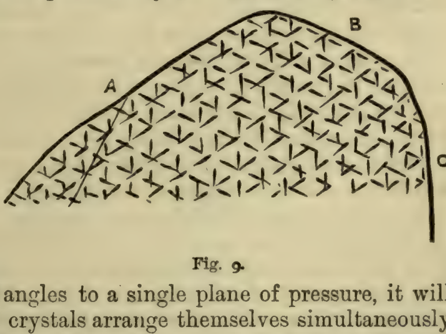


Fig. 9.

crystalline layers at right angles to a single plane of pressure, it will follow that if the different crystals arrange themselves simultaneously at right angles to two or three planes of pressure, their disposition in parallel layers will be interfered with, and the materials must become mixed more or less confusedly together. And this is exactly what happens in the central axis of a mountain, where the pressure is more intense than on the flanks, and comes from both sides of the fold.

[1] Sedgwick, "Structure of Mineral Masses," Trans. Geol. Soc., 2d series, vol. 3.

Thus there are here (fig. 9) three planes of resistance, A, B, C, marked by layers of crystals parallel to each of them, and the result is a confused appearance, in which no single layer can be detected precisely like the aspect of granite. And although owing to the action of resultant forces the particles might not be arranged exactly in the directions here shown, the result would be the same in producing a confused arrangement. Metamorphic granites, according to Professor Haughton, may be seen in Donegal, some parts of Brittany, the Pyrenees, and many other localities.

If now we suppose the rocks forming one of the sides A, B, C, to have fractured, and to have opened in a fissure before the granite was consolidated and cooled, then the pasty granitic rock would penetrate into the fissure and form an intrusive granite vein. Such veins may be seen at Cape Wrath, and in many parts of Scotland, in Cornwall, and wherever granite occurs. Granite usually presents, where exposed, more or less rounded outlines in the scenery.

Fig. 10.

We are now able to advance one step farther and appreciate the close relation between granites and lavas. The central cores of many old volcanoes of the Auvergne in France, and of the Hebrides, are found to be granite; and when this rock cools more rapidly, as at the earth's surface under the pressure of the atmosphere, the minerals no longer form separately, but constitute rock, consisting more or less obviously of a felspathic matrix in which crystals may occur. When poured out in a lava stream these rocks are called felstones, and when they assume a looser texture become scoriæ or ashes. If now we suppose the rocks over a central granite mass to become fractured through their thickness so as to allow water to penetrate down to the heated mass, and to form a funnel or vent out of which the heated materials may escape, it is obvious that the central crystalline rocks will throw out lavas and ashes which may build up a volcano. Thus it follows that clay, slate, gneiss, granite, felstone, rhyolite, may all exist simultaneously as different conditions of the same rock, which have been produced in sequence to each other by the pressure which also brings mountains into existence, and changes the outlines of land and water. This ideal section (fig. 11) will illustrate the relations of the several kinds of rocks to each other, and show the order in which the several classes of rocks may succeed each other on the flanks of a mountain range. Formerly all the igneous rocks were classed into two groups—first, volcanic, or eruptive, which had burst out from beneath the earth's surface; and secondly, plutonic or crystalline rocks which cooled at great depths, and under great

pressure in the earth; but no clear line of demarcation can be drawn between these groups, because the conditions of eruption and consolidation are such that every possible gradation of pressure and slowness of cooling must be presented by varying circumstances.

It is probable that every kind of plutonic rock has its volcanic

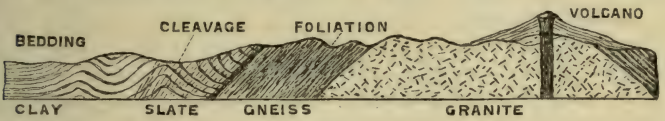


Fig. 11.

representative; but the volcanic form which the plutonic rock assumes has not always been identified. Long since it was observed throughout Europe that the older Tertiary volcanic outbursts were of the kind of volcanic rock which is called trachyte, while the later outbursts are basalts. And this observation led to an attempt to classify the igneous rocks into two classes, of which these rocks are types, according to certain differences in chemical composition which governed the appearance in them or absence of certain materials. The important variable constituent was found to be silica. In the basalt family this substance usually forms 45 to 55 per cent. of the rock; while in the trachyte family the silica may be 60 to 80 per cent., or more. This is an artificial classification, but is convenient in obtaining a general idea of the relations of the rocks to each other; because when the quantity of silica is small, quartz does not form in separate crystals, and only those varieties of felspar are produced which contain little silica; and augite or hornblende is more frequently formed than mica. This division was made by Bunsen, who named the group which contains but little silica, Basic, and that which contains much silica, Acidic. The association of minerals together is almost always a consequence of the original chemical composition of the mass out of which they were formed; thus, Cotta remarks, quartz and mica occur together; orthoclase quartz and mica; orthoclase or oligoclase and hornblende; labradorite and augite; but quartz and augite rarely, if ever, are associated. Many of the volcanic rocks appear to owe their varieties to the influence of heated water penetrating to great depths, which has dissolved the silica and certain other minerals met with in its course, and added these to the heated mass, which was afterwards poured out at the surface. And since such large quantities of salts are dissolved in the waters of mineral springs, it is impossible to over-estimate the changes which may be produced by this means in deep-seated heated rocks, and it may sometimes be the true explanation of the circumstance that when the two classes of lavas occur together, the older series is often the richer in silica. We now propose to give a short account of some of the chief varieties of the principal groups of igneous rocks, enumerating a few localities in which they occur and may be studied. All igneous rocks are divided first into those which contain orthoclase, and secondly, those formed by plagioclase; each of these groups includes two families, quartz-bearing and quartz-free.

The Family of Quartz-orthoclase Rocks.

Typical granitic rocks are all perfectly crystalline. The felspar crystals all touch each other without any intervening uncrystalline material; they may be minute when cooled rapidly, or some inches in length if cooled slowly, when the rock is said to be porphyritic. As a rule felspar is the only mineral in which the crystals are large. Many of the quartz crystals, as was first discovered by Mr. Sorby, contain cavities with a globule of liquid and a bubble of air;[1] and on their characters an estimate has been made of the pressure under which granite consolidated, as represented in thousands of feet of overlying rocks which have since been removed. In Cornwall this pressure has been stated at 50,000 feet, in the Grampians at 78,000 feet, while in the Lake Country the pressure is considered to have been less. There are five or six chief varieties of rocks of the granite group which agree in containing quartz, besides many other local varieties, resulting from original differences in the rocks which were thus metamorphosed.

In this country granite is the only rock of the series that will come under the notice of the physical geologist as forming an important element in scenery. In London, examples of some of the chief varieties may be seen in a worked condition in the following public buildings:—Thames Embankment, London Bridge, Waterloo Bridge, Club Houses in Pall Mall, pillars in front of St. Paul's Cathedral, Midland Station and Euston Station.

NAME.	COMPOSITION.	LOCALITIES, BRITISH OR FOREIGN.
Granite	Quartz, orthoclase, mica, sometimes oligoclase also.	Dartmoor, Bodmin Moor, St. Austell, Falmouth, Land's End, Shap, Eskdale, Peterhead, Aberdeen.
Syenitic granite	Quartz, felspar, mica, hornblende.	Charnwood Forest, Ennerdale and Buttermere.
Protogine	Quartz, felspar, mica, talc, or chlorite.	The central mass of Western Alps.
Luxulianite or Schorl-granite	Quartz, felspar, tourmaline, with some mica.	Erzgebirge, between Schneeberg and Eibenstock, Luxulian in Cornwall, Predazzo in Tyrol, and near Heidelberg.
Haplite	Quartz, orthoclase.	Tharand in Saxony.
Greisen	Quartz, mica.	Zinnwald in the Erzgebirge.

[1] Quart. Journ. Geol. Soc., vol. xiv. p. 453.

The Felsite and Rhyolite Series of Imperfectly Crystallised Granitic Rocks.

When the materials which would otherwise have constituted a granitic rock solidify under moderate pressure or quickly, then a large part of the rock remains in the form of a paste, which to the unaided eye appears to be uncrystalline. This paste, in old rocks, is termed felsite. In some felsites crystals of quartz, felspar, and mica, &c., occur, but in others crystals have hardly ever or never been formed. Quartz-felsite is an ancient Rhyolite.

NAME.	COMPOSITION.	LOCALITIES.
Granite-porphyry	Compact felsitic matrix with crystals of quartz, felspar, mica, or chlorite.	Drusenthal and Schmiedefeld in Thuringia.
Elvanite or quartz-porphyry	Compact felsitic matrix with crystals of quartz and felspar.	Cornwall, at Penzance, near Marazion, &c.
Felstone or felsite-rock Petrosilex or Eurite	Compact felsitic matrix sometimes with crystals of quartz and felspar. An ancient rhyolite or trachyte.—Silica 70–80 p. c.	North Wales, &c.; Skye, Mull. On the flanks of granite it is termed felsite schist or Hälleflinta.
Pitchstone	A vitreous condition of any of the preceding rocks, but contains more combined water. Often contains balls of felsite, and sometimes crystals of sanidine, quartz, and mica.—Silica, 63–70 p. c.	Arran, Rum, Mull; Mexico, Peru, Iceland, Auvergne.
Rhyolite, or quartz-trachyte	A compact felsitic matrix, with crystals of quartz, sanidine, and mica. Hence formerly named trachyte-porphyry.	Lipari Islands, Ponza Islands, Euganean Hills, Schemnitz in Hungary.
Perlite	An enamel-like grey rhyolitic rock, containing concentric grains like pearls, with occasional crystals of quartz, sanidine, and mica.	Lipari Islands, Schemnitz in Hungary, Tokay, &c.
Obsidian	Dark volcanic glass, often with crystals of sanidine, and sometimes balls of felsite.	Lipari Islands, Peak of Teneriffe, Iceland, Mexico.
Pumice-stone	Obsidian converted into a froth by the multitude of steam cavities which it contains. It is always white.	Generally with obsidian but sometimes without it, as at the Laacher See, near Andernach, on the Rhine.

Like the granites these rocks are of all geological ages. Felstone appears to be a form in which granite consolidates when, having been poured out as a lava stream, it cooled under water. Felstone rocks from North Wales are commonly used for paving the roadways in many parts of London.

The Family of Quartz-less Orthoclase Rocks.

Syenite might be grouped with the granites which it resembles in external appearance, because the conditions of consolidation were the same. But as it does not contain quartz, it is evident that the strata which were metamorphosed to form it must originally have been dissimilar. Typically, syenite contains hornblende ; but occasionally the hornblende is replaced by augite, or in Calabria by mica. The mica-syenite of Rosenbusch is the minette or mica-trap of authors. Professor Bonney regards mica-trap as a family in which he places minette-kersantite, minette-felsite, mica-diorite, and kersantite-porphyrite. Augite-syenite, like mica-syenite, is chiefly known in dykes. The volcanic representative of hornblende-syenite is beyond doubt trachyte ; though trachyte, like rhyolite, contains glassy felspar, instead of the opaque orthoclase of the plutonic rocks.

Trachyte differs from the granite series in the circumstance that most varieties of the rock do not contain crystals of quartz ; or when quartz is present, it is in a form named tridymite. The percentage of silica in the rock does not fall much, if at all, below that of granite ; and the trachytes are closely related to the granites. In North America quartz-trachytes are recognised. Trachytes properly so called are rough crystalline rocks ; they occur as lava streams, but sometimes the crystalline trachytes form mountain masses.

These rocks are probably of all geological ages, though the true trachytes have hitherto only been met with in the newer rocks, being represented in the older series by quartzless felsites. We group phonolite with syenite, because it bears much the same relation to nepheline-syenite that felsite and rhyolite hold to granite.

NAME.	COMPOSITION.	LOCALITIES.
Syenite	Granular crystalline mixture of orthoclase and some oligoclase, with hornblende and magnetite. Many syenites contain mica, quartz, nepheline, or augite.	Charnwood Forest, Dresden, Guernsey.
Zircon-syenite	Granular crystalline mixture of orthoclase, nepheline, zircon, and a little hornblende.	Laurvig and Brevig in Norway.
Porphyrite	A dark felsitic matrix, chiefly of oligoclase or orthoclase, with crystals of felspar, forming felspar porphyry, or mica forming mica porphyry, or hornblende forming hornblende porphyry.	Elfdalen in Sweden, Lennegebiet in the Harz, often with columnar joints, Thuringian Forest, Pentland Hills, near Edinburgh.
Sanidine trachyte	Granular or compact matrix of sanidine, with crystals of sanidine, hornblende, and magnesia mica.	Lavas of Monte Nuovo, Berkum, near Bonn ; Robertshausen, in Hesse Darmstadt.

NAME.	COMPOSITION.	LOCALITIES.
Drachenfels trachyte	Granular matrix of sanidine and oligoclase, with magnesia mica and hornblende, and large crystals of sanidine. May contain tridymite.	Drachenfels, near Königswinter, on the Rhine; and other localities in the Siebengebirge.
Minette, or mica syenite	A grey felsitic matrix of orthoclase, with much mica, and sometimes crystals of augite or hornblende; chiefly in veins and dykes.	In the Channel Islands. Near Framont in the Vosges, near Oederan in Saxony, and in the Lake district, at Sale Fell west of Bassenthwaite, and Cross How Beck.
Miascite	Granular crystalline mixture of orthoclase, nepheline, sodalite, and biotite.	Miask, Ditro in Transylvania.
Phonolite	Compact rock, rings under the hammer, weathers white like felsite. The matrix consists of sanidine, nepheline, hornblende, titanite. Crystals of sanidine occur more developed. Sometimes oligoclase is a constituent. Occasionally vesicular and amygdaloidal.	Wolf Rock. Mileschauer in Bohemia, Aussig in Bohemia. Forms conical isolated hills in the Mittelegebirge of Bohemia; in the Auvergne, as at the Roche Sanadoire.

Family of Quartz-bearing Plagioclase Rocks.

These rocks are as distinct from the ordinary plagioclase rocks, as are quartz orthoclase rocks from the quartzless series, but they are less frequently met with.

NAME.	COMPOSITION.	LOCALITIES.
Quenastite or Quartz-diorite	A granular compound of quartz, plagioclase and hornblende, with orthoclase in some localities.	Quenast in Belgium, Catauzara in Calabria. In the Tonale Pass in the Tyrol is a micaceous quartz diorite.
Quartz-propylite	A micro-crystalline green paste of quartz, oligoclase and hornblende, with larger crystals of these minerals and titaniferous iron.	Many places in the U.S., such as Papoose Peak, Hills of Golconda, &c., and some places in Hungary.
Dacite or Quartz-andesite	Grey or brown granular or compact matrix of felspar and hornblende, with quartz, oligoclase, sanidine, and hornblende in fine grains or crystals, with magnetite.	Named from the ancient Dacia; found in Transylvania and Hungary.
Quartz-dolerite	A micro-crystalline compound of quartz, plagioclase, augite and olivine.	U.S.A., on the Upper Snake River and Shoshone Mesa.

Family of Quartzless Plagioclase Rocks.

These rocks were formerly included partly as greystones, partly as greenstones, the oligoclase series, except diorite, belonging to the former; while the labradorite rocks with diorite formed the greenstones. Diorite is the deep-seated condition of the andesites, just as gabbro is the plutonic condition of dolerite.

NAME.	COMPOSITION. — OLIGOCLASE PREDOMINANT.	LOCALITIES.
Diorite	Granular compound of oligoclase or labradorite and hornblende; usually dark green.	Brazil Wood in Charnwood Forest, Klumpsen in Oberlausitz, Hulmberge in Thuringia. In the Tonale Pass in the Tyrol is a micaceous quartz diorite.
Domite	Granular matrix of oligoclase, no sanidine, with crystals of oligoclase, augite, or hornblende, and biotite.	Puy de Dome, in the Auvergne. Puy de Sarcouy, Puy de Chopine.
Andesite	Granular or compact matrix of oligoclase, with crystals of oligoclase and augite or hornblende, and sometimes biotite and magnetic iron.	Chimborazo and Cotopaxi. Plateau de Durbiz in the Auvergne and Wokenburg and Stenzelburg in the Siebengebirge.
Augite andesite or Trachy-dolerite	A grey or brown granular matrix of oligoclase, with augite or hornblende, and some mica. Sometimes contains much labradorite.	Peak of Teneriffe, older lavas of Etna, crater of Stromboli. The Löwenburg in the Siebengebirge.
	LABRADORITE PREDOMINANT.	
Gabbro	Granular compound of labradorite or saussurite and diallage or hypersthene. Some gabbros contain olivine.	Cornwall, Mull, Skye; near Penig in Saxony. Common in dykes.
Dolerite and basalt	Labradorite and augite, usually with olivine and titanite, and sometimes nepheline. The volcanic condition of gabbro.	In dolerite the grains are distinct; when the grains are very fine it is anamesite. If the texture is compact the rock is basalt; when glassy it is tachylyte. Well seen in Antrim, Skye, Mull, Eigg, Arthur's Seat.
Diabase	A dolerite of Primary age in which chlorite or serpentine is developed by decomposition.	Sweden, Berneck, and Saalburg, in the Fichtelgebirge; the Harz. In Britain all the basalts of Cambrian or Silurian age are diabase.
Nepheline-dolerite	Nepheline and augite with titanite, &c.	At Meiches in Hesse, Katzenbuckle in the Odenwald.
Leucite basalt	Leucite and augite with titanite, &c.	Lavas of Monte Somma. lavas of Vesuvius in 1828 and 1832, Bell near Andernach.

Most basalts were lava streams. The rocks are now often columnar, or have a spheroidal or tabular structure. They are sometimes full of natural air cavities, and are then said to be vesicular or scoriaceous. When these cavities are infiltrated with minerals, the rocks are termed amygdaloids. Behind Tobermory in Mull, these white infiltrations are so numerous that the rock looks as though splashed over with whitewash. The infiltrated minerals, which may form two-thirds of the rock, are collectively termed zeolites. They have been formed by the water which percolated through the rock dissolving the felspars, &c., and redepositing them chemically combined with water. Basaltic rocks may contain large crystals; they also form volcanic ashes. There are many minor varieties of rock chiefly named from the zeolites which enter into their composition.

The preceding tables of the igneous rocks will be sufficient to enable us to estimate the part which they take in forming the earth's surface, though they give necessarily but an imperfect idea of their varieties. Any classification into which they may be grouped must always be a matter of convenience rather than an expression of the necessary combinations of minerals into rocks, if we believe that the materials of igneous rocks were originally the materials of stratified formations. For the sorting power of water gives a differing mineral composition to almost every mile of a formation as it recedes from shore. If the whole deposit on the sea-bed were afterwards melted up and ejected as lava, it would result that the parts near to land would be rich in silica, and would contain the minerals in which silica abounds, forming the quartz-bearing or so-called acidic rocks; while the parts more distant from land, such as certain clays, would contain the minerals in which silica is deficient, and form the so-called basic rocks. It may be artificial to classify either by the quartz or the felspar in igneous rocks, but this is a chemical classification also. At present we are unable to discover how those strata were spread and composed, out of which igneous rocks have been reconstructed. Obviously there must be many gradations of mineral character in the igneous rocks which cannot be detected, on account of the fragmentary way in which they burst through the earth's surface or become exposed by the removal of superincumbent rock; and these transitions would probably be as complete were they known, as are the gradations of texture in the rocks which result from differences in the conditions under which they cooled; which permit the same original rock substance to become a mass of large crystals, finely crystalline, compact like biscuit china, glassy, vesicular, scoriaceous, or ashy; or when vesicular to be so altered by infiltration that its whole character is changed. We must bear in mind that while the liquefaction of sandstones would give certain granitic rocks, and liquefaction of clays would yield the greenstones, these materials may often be so contorted and folded together with limestone, that the igneous rock resulting from their fusion would be intermediate in character, or combine minerals which are usually limited to different groups of rocks.

The Joint-Structure of Igneous Rocks.

When igneous rocks cool they all contract, and thus fissures which are called joints appear in them. These joints run through the rock in different directions, according to its composition and the conditions under which it cooled; and sometimes the same rock presents two or three kinds of joints, or it shows no joints at all. In granite, the prevalent joints run in straight lines which cross each other at some angle; and in basalt, phonolite, and some other rocks, the joints often form six-sided columns, which may be straight or curved, and vary from an inch or two in diameter up to a width of many feet. Some of the largest may be seen at the old basalt quarries now used for beer-cellars at Nieder-mendig, not far from the Laacher See, on the Rhine. An excellent account of several kinds of joints in volcanic rocks has been given by Professor Bonney, under the names of columnar, tabular, curvi-tabular, and spheroidal structure.[1] There is no doubt that some joints are a consequence of conditions under which the rock cools, but the forms and directions which they assume have always some predisposing cause, usually pressure or strain. The joints in granite could not be accounted for by cooling alone, unless it were supposed that cooling took place from opposite sides of the mass, so that the shrinkage planes formed on one side have intersected those formed on the other side. And it seems likely that jointing is primarily a consequence of the development of shrinkage planes in the direction of the predominant arrangement in the rock of its principal mineral constituent. Thus more than half of granite consists of orthoclase felspar, and if the majority of the felspar crystals have a prevalent direction, consequent either upon pressure or contraction, then there must have been a tendency for the rock in cooling to behave as though it consisted entirely of felspar, and to divide by joints which correspond more or less with the cleavage planes of orthoclase or with its crystalline faces. And when we bear in mind the circumstance that in granite the minerals have been arranged in at least two directions, it becomes probable that the felspar crystals should have more than one direction, so that a second set of cleavage planes may be produced running through the other minerals associated with the felspar; and this may be the explanation of the fact, that in most granite quarries the joints which correspond with orthoclase cleavage are crossed by others, which at first sight seem to be inconsistent with it, and correspond better with the angular directions of the crystalline faces. In the same way the other kinds of joints might be regarded as consequences of the influence of the rate of cooling upon the mode of arrangement of the predominant mineral forming the rock. Professor Bonney mentions the occurrence of a kind of columnar structure in ice, in hæmatite iron-ore, in a large quartz vein at Svolvaer in the Lofoden Islands; in coal where it is in contact with basalt, in volcanic mud beneath basalt at Tideswell Dale in Derbyshire, in the consolidated pelagonite ash of Iceland; besides finding it in the trachyte of Mont

[1] Quarterly Journal of the Geological Society, vol. xxxii. p. 140.

Dore in the Auvergne, the pitchstone of Arran, the felstone of Cader Idris, and phonolite of the Rochte Sanadoire in the Auvergne. Mr. Koch has stated, that when some slags are cooled under water they also assume a columnar structure. The hexagonal structure of ice, hæmatite, and quartz would seem to be connected with the fact, that those minerals crystallise in the hexagonal system, and circumstances have favoured their division into hexagonal prisms.

But the prevalent columnar structure of basalt is of an altogether different nature. The surface or the floor of the lava stream cooled uniformly, and therefore contracted, so that the cracks appeared near the surface or base, and penetrated deeper and deeper as the cooling progressed; sometimes leaving an undivided portion in the middle of a thick lava-flow. And it is extraordinary that these cracks always form an angle of about 120° with each other, so that the entire mass of rock is split up into six-sided columns. Both the augite and labradorite which form basalt, belong to the monoclinic system of crystallisation; and we think it possible that the angles of the skeleton-crystals of the augite and felspar have determined the angle of the division planes splitting basalt, causing the columns to take a six-sided figure, rather than any other form, so that the structure itself is essentially crystalline.

When basalt has been exposed to the weather, as in the Giant's Causeway and in Staffa, the columns are often found to be divided transversely by joints, which have been compared to the joints in the back-bone of a shark. And sometimes the outer layer of each of these short pieces scales off, showing an internal concentric structure. This is beautifully seen at the grotto called the Käskeller, near Bertrich, by the Moselle, where the columns look as though built of Gouda cheese. But a similar though irregular joint-structure may be seen almost as well, on a small scale, in the country above Tobermory in Mull, where many thin concentric layers of compact basalt will scale off from the irregular blocks, leaving in the centre a small, rough, more crystalline ball, with the texture of dolerite. Up the Rhine from Bonn to Andernach, basalt columns do not usually show transverse divisions, but are often enormously long, and have to be broken into convenient lengths for the various building purposes for which they are quarried.

CHAPTER V.

THE NATURE, COMPOSITION, AND ORIGIN OF THE COMMON WATER-FORMED ROCKS.

ALMOST the whole of the land surface of the world consists of rocks which have been accumulated under water. It nowhere shows a trace of such materials as would have resulted from an original igneous fusion; for such surface rocks would have been uncrystalline and like modern volcanic lavas. Only occasionally are large masses of crystalline rocks seen, and those are only exposed by the water-formed rocks which covered them having been removed by the denuding power of water. Though volcanoes are numerous, the areas of the earth's surface covered with sheets of lava poured out from the earth in a molten state are not very considerable. The whole land surface consists of materials which may be classed as superficial volcanic rocks, deep-seated crystalline rocks, and stratified rocks, which have been spread out under water in layers. The stratified rocks can be accounted for directly or indirectly as products of the wear and tear of the other kinds; and it is almost equally certain that the aqueous rocks may be changed by pressure, and the heat to which pressure gives rise when it is arrested, into the more or less crystalline rocks which are severally named Metamorphic, Plutonic, and Volcanic. We have no means of judging what the earliest-formed rocks were like; and Professor Huxley, with excellent reasons for the suggestion, has remarked that the oldest rocks now known bear the same relation in point of antiquity to those which must have preceded them, that the newest deposits of the geological series bear to the whole series of strata which have been discovered.

Kinds of Deposits.—The water-formed rocks consist of pebbles, sand, mud, or limestone, which have become hardened by various natural cements into solid beds called strata. The pebbles then become a conglomerate, the sand a sandstone, the mud a clay, and the shells, corals, or foraminifera, or other remains of animals, form limestones. These are the chief kinds of water-formed rocks. Pebbles, sand, and clay are worn away by sea, river, or lake water from lands which previously existed, and are spread out parallel to the shore, or at the mouths of rivers. These materials are only held in suspension by the mechanical power of moving water, and hence are often called mechanical deposits; and since they fall as sediments when the

materials can be carried no farther, they are more frequently named sedimentary deposits. Limestone does not accumulate as a sediment. The carbonate of lime can only be taken up into the water when water contains sufficient carbonic acid gas to dissolve it; and water only parts with it again when the surface layer is evaporated, or when some plant or animal separates the lime from the water to form its skeleton. Deposits due to these causes accumulate over the whole bed of the ocean, though their rate of accumulation is so slow that the lime is usually inappreciable near to shore where other deposits are forming, except as a cement, binding sands or hardening clays. These layers of sand, clay, and limestone extend through the country, sometimes turned up from their original horizontal positions almost on end, sometimes bent into basin-shaped folds, and sometimes folded into saddle-shaped ridges. Pebbles are only formed where the rocks on the shore or a shallow sea-bed are hard, and are worn away by the pieces being slowly ground against each other, and thus become rounded. They may consist of any kind of rock, and are usually evidence of near vicinity to land at the time of their deposition. Mr. Darwin mentions that at Santa Cruz, on the sloping east coast of South America, the pebbles near to shore are very large, while at three or four miles from the shore they are as large as walnuts; at six or seven miles, as large as hazel nuts; at ten to eleven miles from shore they were from $\frac{3}{10}$ths to $\frac{4}{10}$ths of an inch; at twelve miles, $\frac{2}{10}$ths of an inch; and from twenty-two to one hundred and fifty miles, the sediment varied in size from $\frac{1}{10}$th of an inch to the finest sand. Over this distance the depth steadily increases to sixty-five fathoms. Many beds of pebbles occur along our own shores, especially where there are chalk cliffs or granite, or other old and hard rocks to furnish materials out of which they may bè formed. According to Colonel Greenwood, pebbles of chalk-flint are carried by the sea as far west as the south of Cornwall, and pebbles of the Cornish rocks are mixed with the flint pebbles of Sussex and Kent. There are many beds of conglomerate among the British strata, as will be seen by a glance at the table given further on.

Mr. Darwin's observations, just referred to, show that the pebbles become smaller farther from shore. The small pebbles are chiefly pieces broken from the larger masses, and often are the larger pebbles worn small by constant rubbing against each other. When they are no larger than peas, the rock they form is often called grit. The British strata contain several such beds; as, for instance, the Millstone Grit, which lies below the formation named Coal Measures.

Sand.—The finer kind of sediment called sand consists of the mineral quartz. This is either the fine dust ground from off flints or old quartz rocks in the process of rounding pebbles, or is made up of grains of quartz, which constitute part of some crystalline rocks such as granite and the schists. These grains are usually bound together with a cement of silica, or carbonate of lime, or oxide of iron, so as to be hardened into stone. The most familiar example of sandstone is seen in the paving-stones which form the footways in London

and many large towns. Sands and sandstones occur in each of the great divisions of the geological series in this country. Among them may be named Harlech Grits, Llandovery beds, Downton Sandstone, much of the Old Red Sandstone formation, much of the Millstone Grit, the Pennant, and many sandstones associated with the Coal. The Permian and Triassic rocks in this country are chiefly sandstones. The Lower Oolites in Yorkshire are largely formed of sandstone. There are also the Portland Sands, sands of the Purbeck and Wealden periods, Lower and Upper Greensand, the Thanet Sands, the Bagshot Sands, and other deposits. Sand and sandstones generally form somewhat elevated and dry country, which is frequently wooded, especially with fir, and is sometimes covered with heather. See p. 92.

Clay.—Clay consists chemically, chiefly of silicate of alumina, and has very nearly the same composition as the mineral felspar, which makes up so large a part of fire-formed rocks. Sometimes when hardened by pressure, and by containing other minerals, the clay is called shale; it then splits into thin layers in the direction in which it was deposited. Clay consists of extremely fine particles which can easily be transported by moving water, as may be seen by the muddy state of rivers after rain in clayey districts. The colour of clay is generally due to some oxide of iron; it is usually grey or blue, sometimes brown, occasionally white, yellow, red, crimson, purple, violet, or black. Clay generally forms valleys and low land; it does not easily allow water to pass through it, but always holds a good deal of water suspended in its substance; and when this is evaporated, large and deep surface cracks and fissures are formed, which may be enlarged by rain into gullies. The older British clays have undergone certain changes, so that it is convenient to give them another name, and they are now termed slates and slate rocks. Some of the well-known clays are the Lias, Bradford Clay, Oxford Clay, Ampthill Clay, Kimmeridge Clay, Wadhurst Clay, Weald Clay, Gault, London Clay, Barton Clay, and Boulder Clay. These deposits are often well wooded, especially with oak, beech, and elm. See p. 99.

Selenite.—Clays sometimes contain a large amount of iron pyrites, which is usually a yellow brassy-looking mineral, consisting of sulphur and iron. When it decomposes, the sulphur is set free in the form of sulphuric acid. This acid, taken up by water, usually dissolves the carbonate of lime of shells, and then the new compound crystallises and forms transparent crystals of the mineral selenite, which is a variety of gypsum, and is composed chemically of hydrated sulphate of lime. The water may be driven off from this mineral by heat, and then, when ground to powder, the substance becomes plaster-of-Paris.

Alum.—In other cases the sulphuric acid, liberated from the decaying iron pyrites, attacks the clay itself, and then forms crystals of alum, which is a sulphate of alumina. This product of the London Clay has given its name to Alum Bay in the west of the Isle of Wight; and it originated the industry of alum-making on the Yorkshire coast, in beds of the Upper Lias, which are hence called alum shales.

Septaria.—Clays also contain concretions formed of a mixture of lime and clay. They are often oblate elliptical spheroids, and are named septaria. In new strata they are very small, and may be seen in process of first formation in little nests in the brick-earth of the valley of the Thames, as at Crayford. They are found in nearly all clays, and are larger in the older rocks, showing that they grow gradually by gathering to themselves, by the solvent action of water, the lime which the clay contains. In the London Clay they are usually a foot or two in diameter; and in most of the clays are under six feet across. Brickmakers often call them turtle-stones. In the Ludlow rocks they are called ball-stones, and are sometimes eighty feet in diameter. When burned and ground to powder these concretions form hydraulic cement, which sets under water. Septaria are so named from the partitions or septa by which they are divided. They owe their existence to the fact that while the clay was forming, lime also was being thrown down upon the sea-bed, but in quantity too small to form continuous beds of limestone. And proof of this is seen in the fact that layers of septaria, which cover the clay-floor much as raisins might cover a surface of dough, may sometimes be traced into more or less continuous beds of rock. These concretions are rarely or never met with when the clay is sandy. See p. 102.

Phosphatite.—Occasionally beds of small concretions of phosphate of lime, sometimes called coprolites, rest on clay surfaces or are scattered in sands or limestones. They are highly valued for the manufacture of an artificial manure for root-crops, which is named superphosphate of lime. The chief phosphatic beds in this country are six in number: in the Bala series of North Wales, in the Upper Neocomian, Gault, Upper Greensand, Coralline Crag, and the Red Crag of the south-east of England. These deposits appear to have been owing chiefly to the growth and decay of sea-plants for many generations, on fixed spots near to the shore, since those plants all contain a quantity of phosphates, which are capable of combining with lime when liberated by the decay of their organic tissues. These concretions rarely assume a septarian structure; and the mineral often invests or infiltrates animal substances. See p. 103.

Limestone.—Limestones consist of the mineral calcite, though usually in an uncrystallised condition. River waters carry dissolved a good deal of carbonate of lime, and Sir Charles Lyell has recorded that the evaporation of the waters of the Rhone which float over the sea is forming a calcareous rock off its delta, in which sunken cannon had become embedded. At the base of chalk cliffs the chalk is always rounded into large boulders, as may be well observed at the Culver Cliff on the east of the Isle of Wight; and the peculiar green colour of the sea-water off chalk coasts has been attributed to the particles of abraded chalk which it contains. Such particles may be presumed to form a deposit in which small chalk pebbles occur; for a reconstructed limestone bed of this kind may be seen in the geological deposit called the Stonesfield slate.

Oolite—Another group of limestones is the oolites, so called from

their resemblance in structure to the eggs or hard roe of fish. The grains are rarely $\frac{1}{10}$th of an inch in diameter, are spheroidal, cemented together with carbonate of lime, and when sliced and examined under the microscope, are seen to consist of concentric layers of crystalline calcite, arranged about a nucleus, which is sometimes a grain or two of sand, but more frequently a minute foraminiferous shell. Occasionally the grains are radiate, and sometimes they have recrystallised. This structure is seen in some parts of the Bala limestone, and occasionally in the Plymouth limestone, and parts of the Carboniferous limestone near Bristol, &c.; it is characteristic of much of the Inferior Oolite, Lincolnshire limestone, Bath oolite, Coralline oolite, and Portland oolite. Oolitic grains occur in Tertiary freshwater limestones of the Isle of Wight. Von Buch has mentioned a stalactitic layer of limestone, which is sometimes oolitic, covering the lavas of the island of Lancerote. It has been suggested that the deposit is due to north-west winds in winter, driving the spray of the sea over the island. A similar rock is described by Mr. Darwin at St. Helena, where masses of white finely oolitic rock are attached to the outside of some of the incrusted pebbles; and Mr. Sorby has described oolitic grains in the recent limestones from Bahama and Bermudas. Concretions of a concentric nature, but of far larger size and darker colour, are formed at Carlsbad by the waste water of the hot mineral spring. In these recent instances the grains may have formed in a subaerial way; but in the case of the great Secondary limestones, there can be no doubt that their formation is due to evaporation of the surface of the sea, so that a film was formed around some shell fragment, and continued to increase in size as it fell through the water till it sank to the bottom. This explanation will also account for the uniform size of the grains in the same stratum, Sometimes beds occur, like the Pea Grit, at the base of the Inferior Oolite. in which the grains are as large as peas, and often of irregular shape.

Foraminiferal Limestone.—Many limestones are composed chiefly of the remains of animals, such as corals, foraminifera, shells, encrinites, &c. The chalk is the best example in this country of a foraminiferal limestone; but the limestones formed by the *Miliola*, and especially by the *Nummulina*, constitute great beds on the Continent, and the latter ranges east and west through the central region of the Old World. Deposits like the chalk are now forming at the bottom of all the deep oceans, chiefly by the accumulation of foraminifera named *Globigerina* and *Orbulina*, with a few pteropods which also live in the surface waters, and sink to the bottom after death to become mixed with sponges, sea-urchins, shells, and crustaceans, which live at great depths.

Coralline Limestone.—Among the limestones in this country, largely formed of corals, are the Wenlock limestone of the border counties of Wales, the Plymouth limestone of South Devon, parts of the Carboniferous limestone, especially of Derbyshire, and the Coral Rag. Probably all these corals lived in moderate depths, for there is no evidence that they formed great coral reefs, such as exist at the present day, and extend down to great depths in the ocean. The

individual coral growths are mostly small, and as in a coral reef are usually mixed with abundant fragments of worn corals and other calcareous masses; all are commonly bound into a solid mass by carbonate of lime deposited from the water soaking through the rock.

Shell Limestone.—One of the best English illustrations of a shell limestone in process of formation in shallow water, is seen at Shell Ness at the east of the Isle of Sheppey, in the Thames. There shells are cast up so as to form a considerable level deposit, which in time may well become cemented into a stratum like many of the shell beds in the Carboniferous limestone and Lower Oolites. In some formations, like the Headon series in the north-west of the Isle of Wight, there are considerable oyster-beds which have continued to grow and accumulate although the mineral character of sediments around them has changed several times; just as oyster-banks grow at the present day on the floor of the English Channel regardless of changing currents.

Other limestones are almost entirely of vegetable origin. On certain shores, especially in the tropics, plants called *nullipores* grow, which, by absorbing carbonic acid from the water, have the power of precipitating around their tissues a dense coating of carbonate of lime. They are slender, stony-looking, jointed tufts, termed corallines, and abundant on our own shores, but with the joints growing to the size of fingers on coral reefs, to the building up of which they contribute a not inconsiderable fraction.

Freshwater Limestones, &c.—In our own fresh waters there are plants of the genus Chara, which thrive wherever waters contain much lime, and possess a similar property of separating it from the water of the pond, river, or lake, to that exhibited by the Nullipores. The stem of the plant becomes coated with an incrustation, which ultimately bears the plant to the bottom of the lake or stream, and so contributes to build up a bed of limestone. Many of the limestones in the freshwater strata of the Isle of Wight, have originated in this way. Limestones generally form ridges of more or less rounded hills, intersected with deep valleys, which have been dissolved by rain water as it has drained over the surface. The rounded contours of chalk hills are an excellent example of the scenery produced in this way. Usually limestone hills have but little wood growing upon them. See p. 105.

Simultaneous Origin of Water-formed Rocks. — These several kinds of water-formed rocks are all forming at the present day in lakes and on different parts of the sea-bed; and in all past ages rocks consisting of these different mineral materials have accumulated simultaneously in different regions; so that a formation which is clay in England may perhaps be sand in France, or a sandstone in this country may be represented by a limestone in Germany. We shall the more readily understand how this is possible if we imagine a coast or an island in process of being worn away by the sea, and suppose it to be composed entirely of some crystalline rock such as granite. This rock consists of three minerals, named quartz, orthoclase felspar, and mica, as already described. Speaking roughly, these minerals are combined in granite in the proportions 25 per cent. of quartz, 55 per cent. of felspar, and 20 per cent. of mica. The quartz is a dirty-looking half-transparent mineral, in relatively large particles

called grains, which ordinary water does not easily dissolve; and when the granite becomes softened by exposure to water containing carbonic acid, these particles, which are relatively heavy, are washed out of the rock by rain or the waves so as to form grains of sand. Because this is the heaviest material derived from the wasting of granite, it is carried to a less distance from the shore than other substances, and forms a belt of sand or sandstone parallel to the coast. If granite were the only source of water-formed rocks, and only denuded by the sea, one quarter of all known stratified formations would be arenaceous or sandy deposits. And if the mineral mica, which is a glistening flaky substance, is supposed not to be altered in character or decomposed, it will often be carried to the limit of the sand and help to form what is called a micaceous sandstone, causing the rock afterwards to split into thin layers. But sometimes the mica is carried much farther. More than half of the granite consists of felspar, which forms large milky-white or red crystals. As we have already mentioned, this mineral is chiefly composed of a silicate of alumina; but in granite it also includes some potash, soda, a little lime, iron, and other substances. The carbonic acid, which is always dissolved in water, attacks the felspar by dissolving out from it carbonates of potash, soda, or lime; and then the crystals lose their hardness and become changed into a paste of impalpable fine particles which forms a mud. This mud is held in suspension longer than the sand, and is therefore carried farther out to sea. When it falls to the bottom and is compressed by the weight of water above, it becomes clay, and margins or surrounds the land as an outer belt probably twice as broad as the sand belt. On some coasts, like the South American coast mentioned by Mr. Darwin, there may be no clay deposited within one hundred and fifty miles of land. There is no clearly defined separation between the limits of clay and sand, for they pass into each other from the materials being mixed, and the clays nearest to shore are often micaceous.

When this denudation takes place upon land by the agency of rain, as on Dartmoor, which consists of granite, the sand is left on the slopes of the mountains, while the mud is carried down into the valleys, where it forms pipe-clay. Usually coast and surface denudation go on together, and much of the surface mud is carried away by the rivers; so that the result on the sea-bed is, that as the clay-deposit which was derived from shore denudation approaches a river mouth, the mud which the river brings down causes it to extend out to sea in an expanded fan-like form. So that while the coast clay has its greatest extension in the line of the coast, it follows that the river clay has its greatest extension in the line of the river, which is usually at right angles to the coast. The river clay is also much thicker than the shore clay, for it is the mud derived from a large area of land, and hence it sometimes persists unchanged through several geological formations, while the shore-deposits become altered in their mineral materials. There can be no doubt that the rusty colour of many sandstones is due to the decomposition of mica after it was deposited, so that the iron was set free as an oxide.

Other minerals which occur abundantly in some crystalline rocks, such as hornblende and augite, yield iron ore, and whenever volcanic rocks, especially basalts, decay, a deposit of iron ore is formed from the iron they contained. Professor Ramsay has, in North Wales, shown that the volcanic rocks associated with the Tremadoc beds, on being traced to some distance, pass into a deposit of pisolitic iron ore; and a relation has been observed between the iron ores and the basalts of County Antrim in Ireland. These groups of minerals, micas, hornblendes, and augites, also contain a large amount of magnesia, and when a rock like the magnesian limestone or dolomite of the Permian series is met with, it is reasonable to suppose that the magnesia was derived originally from the decay of minerals which contained that substance. The crystalline rocks are also the only known source of lime, and it has already been indicated that the decaying vegetation on the sea-shore charges the water with a sufficient amount of carbonic acid to enable it to dissolve the lime and hold it suspended in an invisible form. Where the rivers bring down much lime, or where the coasts are very slowly worn away, or where animal life abounds exuberantly near to the coast, deposits of limestone accumulate close to shore. The Coralline Crag in the east of Suffolk is an organic deposit of this kind, and deposits similar to that one are said to be forming near to Tierra del Fuego. But when the shore limestone results chiefly from evaporation of the sea, the deposit is necessarily largely composed of materials which have no relation to living structures. And it follows from what has already been said about the distribution of sands and clays, that when we go out to sea beyond the limits to which sediments are carried from the shore, the only deposit forming on the bottom will be limestones, chiefly constructed from the skeletons of animals which live in the ocean.

Horizontal Sequence of Rocks.—We have here been considering in a general way the order in which deposits become arranged on the sea-bed when the parent rock is granite or some such crystalline substance. Bearing this in mind, it will be evident that as the shore is receded from, *there is a necessary horizontal sequence of rocks in the order: sand, clay, limestone.* Of course, it is possible that the coast might consist entirely of quartzite, which is a rock formed of quartz, when no clay could possibly be produced by wearing it away; or the shore rocks might be formed of lavas in which little or no quartz exists in grains, and then of course no sand can be produced, and the whole rock will break up into clay. And irregularities of the sea-bed and animal growth may cause limestones to accumulate which are quite independent of the positions of clays and sands. Such deposits, however, are rather the exception than the rule. And it may be held as generally true that all crystalline rocks decay into materials which become sandstones, clays, and limestones. And when a cliff composed of layers of these rocks, like the Yorkshire coast, comes again to be worn away and separated into the mineral substances of which it consists, the materials will be sorted out as before and rearranged parallel to the coast in the order—sand, clay, limestone. There are many examples

of such reconstructed deposits in the British strata, but they may generally be detected by containing fragments of the old rocks and fossils which belong to more ancient periods. Thus the Portland oolite of Dorsetshire includes many fossils derived from the Carboniferous limestone; the Neocomian sands of Bedfordshire and Cambridge contain some fossils which may have been derived from the destruction of the upper part of the oolitic rocks. The Red Crag of Suffolk contains fossils derived from many of the Secondary and Tertiary strata. While in the Boulder Clay, rock fragments and fossils may often be obtained from an immense variety of formations.

Vertical Sequence of Rocks.—We may carry this generalisation concerning the order of horizontal deposits one step farther by remarking that as pebble beds and sand form near to shore, and clays and organic limestones farther out to sea, we have in the mineral character of the deposit a rough means of discovering the general direction in which land existed at the time when a geological formation was accumulating, if we can only determine the horizontal sequence of its mineral material. It follows from the horizontal order of rocks that there must be a similar vertical order or succession in time, because land is always in process of being upheaved or depressed, and is therefore enlarged or diminished in area, so that the positions of the coasts

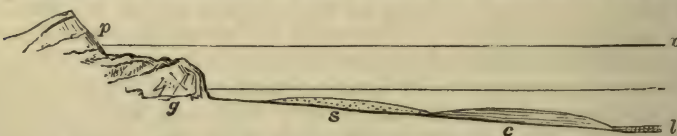


Fig. 12.[1]—Sequence of Deposits on a Sea-bed.

advance out to sea from their former position or retreat in the reverse direction. This may be better understood from a diagram (fig. 12). Here we suppose a coast of crystalline rocks (*g*) to be destroyed by the sea, and the result is seen in the deposit of (*s*) sands, (*c*) clays, and (*l*) limestones. Then if the land (*g*) is depressed so that high-water mark stands at *x*, it follows that the point from which the deposited materials are derived being farther inland (*p*), the sediment cannot be carried by tidal movement so far out to sea. Hence a new sand will be deposited which will be continuous with the old sand (*s*); but since sand can only be carried a definite distance from shore, it results that after the requisite depression no part of the new sand will rest upon the old deposit. And then a new clay will be deposited on the top of the old sand (*s*); and a new limestone on the old clay (*c*). If we suppose, again, the sinking down of the land to progress a stage beyond so that the high-water mark extends further inland, then as the deposits always retain the same order and relative distances from the shore, it results that the sand will accumulate still farther away from the area where we saw it originally (fig. 13); a third clay will be formed upon the second sand, and a third limestone upon the second clay. Here, then, is a vertical sequence of sand, clay, limestone, resulting from the removal of the heavy

[1] Seeley: Annals and Mag. Nat. Hist., December, 1867.

sediments to a greater distance in consequence of the continuous depression and recession of the land from which they were derived.

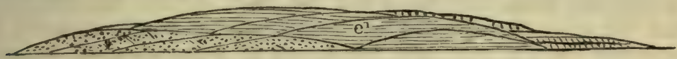


Fig. 13.—Deposits formed when the shore is sinking.

And whenever sediments succeed each other from below upward in this order, it must be regarded as an evidence that the shore-line was receding from the area during the whole period of time which they represent. If, on the other hand, the land which is exposed to destruction by the ocean were to be uplifted, so that the place whence the deposited material originated would go farther out to sea, by denudation of the shore, and the sands near shore, sand would be carried farther out to sea so as to be spread over clay, and similarly clay

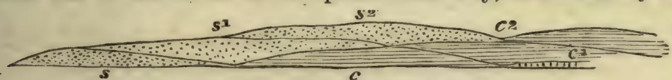


Fig. 14.—Deposits formed when the shore is rising.

would be spread over the previously formed limestone. If, then, the vertical sequence of rocks, limestone, clay, sand, is met with, it may be regarded as evidence that during the whole of the geological time which is represented by those deposits, the land was in process of being upheaved, so that the shore-line was approaching the place where the deposits were forming and are now seen in section in that order. Therefore, since there are necessary limits over which a formation preserves the same mineral character, it cannot be identified over very wide areas by this means. But strata can be traced to distant regions by using this kind of evidence to discover the physical conditions which limited, determined, and changed their mineral characters, and influenced the distribution of life over the geographical areas which they occupy. Hereafter we shall see how these principles are practically applied.

If a formation consists mainly or even largely of sands, we may expect to find evidences that it was deposited in shallow water, and possibly near to shore. Of this we have familiar examples in the ripple-marked sandstones, footprints, sun-cracks, and such like phenomena, which characterise the New Red Sandstone of Cheshire, and parts of the Hastings Sands in Sussex. In the clays we rarely observe any indications of shallow-water conditions; and though land animals and plant remains are often found in clays, these rather indicate the influx of rivers into the ocean than relative nearness to land. Hence it may be inferred that if a clay is superimposed upon a sand, we are entitled to conclude that the coast, which was the source from which the material was derived which accumulated on the sea-bed to form the sandstone below, became depressed in the succeeding age, so that the source of the deposited material was removed farther away, and though sands would have continued to be formed, they were deposited at a distance so far off that the only material which became in the British area superimposed on the sand was the finer flocculent substance which forms

clay. If we further suppose such an ancient coast-line to still farther recede from the district when deposits are going on, so that not only the sand does not reach the area, but the distance is too great for even the clay to be transported so far, then none but calcareous deposits can take place, due to evaporation of water or evaporation combined with the agencies of plant and animal life. It does not follow that the limestones were formed in deep water, it is simply necessary that the sea-bed should be free from sediment, or that the sediment should accumulate so slowly that its importance is lost in the calcareous features of the deposit. Presuming that these general principles are sound, then the lower Secondary strata in the South of England indicate to us a great oscillation in level of the land which furnished the materials for the strata. This may be perhaps best expressed in a tabular form.

Diagram showing the Altered Position of Land in the South of England relatively to the Strata during the Secondary Period.

	Theoretical Horizontal Sequence.	Mineral Character which some of the Strata should present if traced to adjacent areas nearer to the source from which the sediments were derived.	Prevailing Mineral Character of the Formations.	Names of Strata in South of England.	Names of Lithological Groups of Strata.
			Limestone	Chalk	Cretaceous.
			Sand	Upper Greensand	
		Sand	Clay	Gault	
			Sand	N. Down Sand	Psammolithic
		Land	Sand, &c.	Wealden	
			Sand, &c.	Purbeck	
			Sand, &c.	Portland	
			Clay	Kimmeridge Clay	Pelolithic.
Land rising and advancing towards the section.	Land	Sand	Clay, &c.	Ampthill Clay	
			Clay	Oxford Clay	
				Cornbrash	
				Forest Marble	
Land	Sand	Clay	Limestones, &c.	Great Oolite	Oolitic.
				Fuller's Earth	
Land sinking and receding from the section.				Inferior Oolite	
	Land	Sand	Clay	Lias	Lias.
		Land	Sand	Trias	Trias.

On the right of the names of the strata are the lithological names of groups into which they are arranged. On the left of the column of strata are the names of the prevailing mineral substances of which they consist, and in the succeeding columns farther to the left are the theoretical deposits which may be supposed to have taken place in adjacent areas if they were always thrown down in the order here given; and it may be noticed that the land recedes farther from the vertical section from the Trias up to the middle of the Oolites, and then, by elevation, approaches again the area which is now the south of Britain. The Cretaceous rocks are a group of another kind, and include within themselves subdivisions showing three types of mineral character.

Throughout the period of the Psammolithic series, the same rocks continued to be denuded, as is proved by some fossils they contain which do not belong to the formation, but have been derived from older strata. This group in Yorkshire becomes replaced horizontally by a pelolithic representative called the Speeton Clay, which being marine, shows no trace of the minute subdivisions which have been recognised in the South of England, and often made the basis of classification. It is a continuous clay between the top of the Kimmeridge Clay and the lower Cretaceous rocks. Similarly the Pelolithic group in Yorkshire shows towards its base a tendency to become psammolithic in the Kelloway rock, and southward in the section, at Boulogne, its upper part is putting on Psammolithic characters. The Oolitic group when traced towards Yorkshire becomes in the main psammolithic, thus demonstrating the direction in which land existed relatively to the British area which was being covered with these deposits, and enabling us to infer, with the aid of larger knowledge of European formations, the essential directions of the ancient coast-lines.

A Table of the Chief British Strata

Arranged in the order in which they rest upon each other, with an indication of the prevalent mineral character of the beds, and some of their chief variations.

NAMES.	DESCRIPTION.	GEOGRAPHICAL CIRCUMSTANCES OF THE DEPOSIT.
Peat and Bog	Black vegetable growth on land	Still forming, especially in the fens of East of England, in West of Scotland, Wales, and much of Ireland. Contains shell beds.
Valley Gravels and Brick Earth	Gravels, sand, and sandy clay	Formed in present river valleys when they were estuaries, and the level of the land was lower.
Upper Boulder Clay	Clay, with angular fragments of local rocks	Formed by action of ice when the climate was colder, and level of land higher than now.

	NAMES.	DESCRIPTION.	GEOGRAPHICAL CIRCUMSTANCES OF THE DEPOSIT.
	Middle Glacial Sands	Chiefly sands	A marine deposit with Arctic shells, formed when the land was submerged
	Lower Boulder Clay	Clay, with angular fragments of rocks from north and north-east	A formation produced by icebergs and great glaciers from the north.
Upper Tertiary.	Chillesford Beds	Sand and clay	Only recognised in Norfolk and Suffolk.
	Red Crag	Sands and shell beds	A beach, estuarine, and shallow-water deposit; phosphatic nodules at its base.
	Coralline Crag	Sands below, organic limestone above	Formed in a tranquil depth of sea, many shells now found in Mediterranean; phosphatic nodules at its base.
[Here followed a long period of time during which this part of Europe was dry land, and few or no British deposits formed in it are preserved.]			
Lower Tertiary or Eocene.	Hempstead Beds	Clays and marls	Chiefly fresh-water and estuarine, marine above, found only in Isle of Wight.
	Bembridge Beds	Limestone below, marls above	At first lacustrine, then marine, afterwards estuarine.
	Osborne Series	Sands and marls	Chiefly fresh-water and estuarine.
	Headon Series	Alternations of limestones and marls	Alternations of lacustrine and fluviomarine conditions, with a marine bed in the middle.
	Upper Bagshot Sand	Sand	A few marine fossils.
	Barton Clay	Blue clay	Profusion of marine fossils, nearly all extinct, in Hampshire and Isle of Wight.
	Bracklesham Beds	Sand, sandy clay, and lignite	Fossils marine, but some beds of lignite grew where found. Extends to Sussex.
	Lower Bagshot Sand	Sand	Fossil leaves of land plants in beds of white pipe-clay; probably lacustrine.
	London Clay	Clay, sandy at base in Hampshire and Sussex	A marine deposit, near to land at base, middle, and top, with life of an Asiatic type.
	Oldhaven Beds	Rounded pebbles, becoming sands to east	Marine, with current bedding, only found in east of London basin.
	Woolwich and Reading Beds	Sands in east; sands, clays, and pebble beds in middle, clays in south-west	Marine in east, estuarine under London; marine at base in Berkshire; Lacustrine above.
	Thanet Sands	Sands	Thinning to the west, fossils marine.
[Here follows a period unrepresented by any British deposit, but not necessarily of immense duration, although the fossils in the deposits entirely change.]			

	NAMES.	DESCRIPTION.	GEOGRAPHICAL CIRCUMSTANCES OF THE DEPOSIT.
Cretaceous Series.	Upper Chalk	Soft white limestone, with bands of concretions called flints	Marine organic deposit, sometimes 1200 feet thick, formed beyond the limits to which sediment was carried during a period when land was depressed.
	Lower Chalk	Hard white limestone without flints	Organic deposit, formed chiefly of foraminifera, mostly beyond the limit of sediment, but with occasional seams of clay and beds of fine sand.
	Chalk Marl	Clayey chalk	Organic deposit, just within limits of sediment.
	Chloritic Marl	Sandy chalk	Marine deposit, formed not far from land.
	Upper Greensand	Sand and calcareous sandstone with white flint called chert, and phosphatic nodules	Deposit formed near shore; north of King's Lynn merges into the Hunstanton Red Limestone.
	Gault	Blue clay, often micaceous, with much iron pyrites, and phosphatic nodules	Formed at some distance from shore in the south at Folkestone; north of Norfolk probably merges in Carstone, which is called Upper Neocomian.
Psammolithic Series.	North Down Sands, Lower Greensand or Upper Neocomian	Sandstone, with some beds of clay in Isle of Wight	Marine shallow-water formation, which is not separable from the marine representatives of the Wealden and Purbeck in the middle of England.
	Wealden	Alternations of sands and clays, with occasional fresh-water limestones	Almost entirely fresh-water in South of England, probably formed in a lake or estuary, but becoming marine sands north of the Thames, and marine clay at Speeton; sands show footprints.
	Purbeck	Alternations of sands, marls, and limestones	Chiefly lacustrine fresh-water, with some marine beds, merging in the marine Neocomian sands north of the Thames, and represented by marine clay at Speeton; fossil forest in Isle of Purbeck.
	Portland	Sand below, oolitic limestone above	Entirely marine; limestone characters disappear to the north of Oxford, when it forms the lower part of the Neocomian Sands; is clay at Speeton.
Pelolithic Series.	Kimmeridge Clay	Dark blue clay with septaria; is sometimes bituminous	Marine clay, thickens north and south from Ely; is sometimes sandy at top and bottom.
	Ampthill Clay and Coralline Oolite	Ampthill clay is an alternation of clays with earthy limestones	Marine. Ampthill clay occurs between Oxfordshire and Yorkshire; south and north it is replaced by the Coralline Oolite.
	Oxford Clay with Elsworth Rock and Kelloway Rock	Blue clay with limestones near top and bottom; sand at base in north	Marine. The Elsworth Rock is a limestone in Huntingdon and Cambridgeshire near the top. The Kelloway Rock in Wiltshire is a concretionary limestone; in Yorkshire it is a calcareous sandstone at its base, in places.

	NAMES.	DESCRIPTION.	GEOGRAPHICAL CIRCUMSTANCES OF THE DEPOSIT.
	Cornbrash	Thin limestones, with occasional seams of clay	Marine, sometimes shelly; the only bed of the series which keeps its limestone character from Dorsetshire to Yorkshire.
Lower Oolites.	Forest Marble	Thin bedded shelly limestone, with seams of clay	Marine, sometimes ripple-marked; limited to South of England. Represented in middle of England by Blisworth clay.
	Bradford Clay	Brown clay	Marine; only in South of England, probably represented in Northampton, and north, by the upper estuarine sandy clays.
	Great Oolite	White shelly limestones and oolites	Marine; probably represented in Yorkshire by the upper shale and sandstone, and in Oxfordshire by the Stonesfield slate.
	Fuller's Earth	Brown clay and sand, with a middle bed of limestone	Marine; probably represented by the Lincolnshire limestone, and grey limestone of Yorkshire coast.
	Inferior Oolite	Yellow limestones, sometimes oolitic, sometimes marly	Marine; represented by the Collyweston slate, Northampton sands, and lower estuarine beds in Northampton; and by the estuarine lower sandstone and shales on the Yorkshire coast. Worked for iron ore and coal.
	Midford Sands	Yellow and brown sands	Marine; perhaps represented in Yorkshire by the Blue Wick sands, and Dogger series.
Lias.	Upper Lias	Blue clay, with thin beds of earthy limestone	Marine; contains much iron pyrites and jet, and yields alum.
	Middle Lias or Marlstone	Clayey limestones, with micaceous sands, and clays at the base	Marine; distance from shore increased.
	Lower Lias	Thin earthy limestones, alternating with thick beds of blue clay	Marine. The whole Lias formation extends through England, unchanged from Dorsetshire to Yorkshire.
	Rhætic Beds	Sands below, then shales and limestones	Marine, very shallow water. Contains thin bed of fish bones.
Trias.	Keuper	Marls and sandstones above, sandstones below	Probably formed in a salt lake, contains rock salt, and shows ripple marks, footprints of animals, false bedding, and other evidences of shallow water.
	Bunter	Alternations of sandstone, and conglomerates usually red	Contains no marine fossils, but these may have been dissolved away.
Permian.	Upper Permian	Red sandstones	Probably marine, near shore.
	Middle Permian	Magnesian limestone and marl slate	Marine.
	Lower Permian	Red sandstone, marl, conglomerate, and breccia	Probably marine, near shore.

	NAMES.	DESCRIPTION.	GEOGRAPHICAL CIRCUMSTANCES OF THE DEPOSIT.
Carboniferous.	Coal Measures	Alternations of sandstone, shale, ironstone, fire-clay, and seams of coal	Fresh-water estuary and land conditions, very rarely marine.
	Middle Carboniferous	Chiefly thick sandstones and shales, with some coal seams	Marine, but in shallow water near to land, including Yoredale beds, Millstone Grit, and Gannister beds.
	Carboniferous Limestone and Shale	Organic limestones with shales, chiefly at base	Marine; much of it formed of corals, crinoids, and shells living beyond the limits of sediment.
Devonian.	Petherwyn and Pilton Group	Limestones in South Devon, sandstones, micaceous and calcareous, with shales	Marine; represented by Upper Old Red Sandstone north of the Severn, and thought to have been formed in a great lake. Fresh-water shell in Ireland (Anodonta).
	Plymouth Limestone and Ilfracombe Beds	Limestones and shales in the south, chiefly shales in the north	Marine, farther from shore; represented by Middle Old Red Sandstone, which contains many fish related to those now living in fresh-water.
	Fowey and Lynton Beds	Sandstones and micaceous shales, sometimes calcareous	Marine, near to shore; the Lower Old Red Sandstone includes thick conglomerates, and like the whole formation is thought to have been formed in a lake.
Silurian.	Ledbury Shales and Downton Sandstone	Shales above, and micaceous sandstone below	Marine beds, near to land; chiefly seen in the border counties of England and Wales.
	Upper Ludlow Shales	Sandy shales, with thin shelly limestones	Contains a thin bed formed of fish-bones. Marine, distance from land varying.
	Aymestry Limestone	A concretionary limestone, with some beds of shale	Marine; formed when sediment was not abundant.
	Lower Ludlow Beds	Sandy shales and mud stones, with a few calcareous concretions.	Marine; perhaps derived chiefly from decomposing lavas and volcanic materials.
	Wenlock Limestone	Grey concretionary limestone, full of corals and encrinites, with some shale	Marine, chiefly beyond the limit of sediment; sometimes oolitic in Malvern Hills.
	Wenlock Shale	Thick shales, with occasional septarian concretions of carbonate of lime	Marine, distant from shore, but perhaps derived from decaying volcanic rocks.
	Woolhope Beds	Concretionary limestones, with shale and sandstone	Marine, receding from shore.
	May Hill Group, or Upper Llandovery Beds	Brown and yellow sandstones and conglomerates, with a shell limestone called Pentameras limestone	Marine; shore formation.

NAMES.		DESCRIPTION.	GEOGRAPHICAL CIRCUMSTANCES OF THE DEPOSIT.
Upper Cambrian.	Upper Bala Group	Conglomerates and grit above, slates below with the Hirnant limestone	Marine; corresponds with Lower Llandovery.
	Middle Bala Group	Earthy slates and sandstone rocks with Bala limestone near the top, occasionally oolitic	Marine; corresponds with Caradoc sandstone. Includes great thicknesses of lavas, probably derived from small islands not far from land.
	Lower Bala Group	Dark earthy micaceous slates, with thin limestones	Marine; corresponds with Upper Llandeilo flags; thick interstratified volcanic rocks.
	Arenig, or Skiddaw Group	Sandstones and slates, with some shales and pisolitic iron	Marine; corresponds to Lower Llandeilo; thick interstratified volcanic rocks, shallow water.
Middle Cambrian.	Tremadoc Slates	Sandstones, iron-stained slates, shales, flags, and pisolitic iron ore	Marine, shallow water; interstratified with volcanic ash beds.
	Ffestiniog Group	Black slates, iron-stained above, hard sandstones below	Marine; corresponds to Middle and Upper Lingula flags; interstratified are many beds of volcanic ash and lava, sometimes ripple-marked.
	Menevian Group	Black micaceous slates and flags with sandstone	Marine; formerly called Lower Lingula flags.
L. Cambrian.	Llanberis Slates	Purple and green slates and grits	Marine; with clay pebbles in the slates, derived from an older clay formation.
	Harlech Grits	Grits, sandstones, green and purple slates	Marine; evidence in some places of being dry between tides.
Precambrian.	Pebidian	Altered shales resting on conglomerates	No fossils; contains thick volcanic rocks.
	Arvonian	Altered rocks, with a felspathic base, containing grains of quartz	No fossils; largely volcanic.
	Dimetian	Quartzites, and altered shales and limestones	No fossils yet found; largely volcanic.

CHAPTER VI.

PETROLOGY.

Stratification.

SUPPOSING that the student has made himself acquainted, by examination, with the more common and important rocks, as limestone, sandstone, and clay, various kinds of slates, basaltic, porphyritic, and granite rocks, we proceed to inquire in what manner they are arranged in the earth.

The best way of prosecuting this inquiry is to examine sections in the field, open railway cuttings, quarries, and natural sections in the cliffs on the seashore; comparing one area with another, so as to class the phenomena and deduce general results.

The stratification of the aqueous rocks is the basis and foundation of all geological investigation—the great problems and deductions of the science are based upon a clear understanding of lamination, bedding, and stratification.

Arrangement of Rocks on the Surface.—It might be very excusable before countries were cleared and cultivated, and before their various mineral productions were employed and understood, to imagine that the materials of the earth were heaped together in confusion; but at present such a notion will not stand the test of a moment's reflection. One district has chalk beneath the surface, another limestone, a third coal, and a fourth granite, and these are never mixed or confounded together; so that the most careless observer must conclude that the different rocks are arranged after some definite and ascertainable method. These different rocks are not mere insulated patches irregularly scattered through the country, but generally connected on or beneath the surface in long ranges, which, as in the eastern half of England, have their prevailing direction or strike from north-east to south-west. Thus the chalk of the Yorkshire wolds is prolonged through Lincolnshire, Norfolk, Suffolk, Bedfordshire, and Wiltshire, into Dorsetshire, Sussex, and Kent; the oolitic limestones range through Lincolnshire, Northamptonshire, Gloucestershire, and Somersetshire; and many other limestones, sandstones, and clays hold a parallel direction. Hence it is that in proceeding from London toward the south-west, west, or north-west of England, we cross so great a variety of rocks and formations, and so many ranges of hills.

On proceeding from London to North Wales, after passing low,

gravelly plains in the drainage of the Thames we climb by a long slope the chalk hills of Oxfordshire, cross vales of clay and sandstone, ascend a range of oolitic limestone, traverse wide plains of blue and red marl, arrive in districts where coal, iron, and limestone abound, and finally see Snowdon composed in great measure of igneous rock, slates, and sandstones. And if, in proceeding from London to the Cumberland Lakes, we find the same succession of gravelly plains, chalk hills, clay vales, limestone ranges, blue and red clays, coal, iron, and limestone tracts, succeeded by the slate rocks which compose the well-known mountain of Skiddaw, we conclude that something beyond mere chance has brought together these rocks with such perfect sequence and order. May we not reasonably conjecture that also in the *interior* of the earth regularity of structure must equally prevail?

Internal Arrangement of Rocks.—This conjecture becomes certainty when we explore the relative position of rocks as displayed in pits, quarries, railway cuttings, mines, and wells, or laid bare in cliffs and ravines by the hand of nature. Here we see the rocks formed in layers, strata, or tabular masses of various thickness, but always of very great superficial or horizontal breadth or extent, and placed parallel to or upon one another like the leaves of a book. These layers are called strata. Along the edges and flanks of hills, in the course of precipitous valleys, and by the margin of the sea, in the form of cliffs, it is not difficult to recognise these facts or truths,—it is almost impossible to avoid perceiving them.

Many parts of the English coast present what is termed a natural section of the rocks, and accordingly whoever visits the shores of Northumberland, Yorkshire, Kent, Hampshire, Dorsetshire, Cornwall, South Wales, or Cumberland, may easily observe for himself the stratification of most of the limestones, sandstones, clays, and slates of the different geological formations exposed. For most of the cliffs are composed of distinct layers of rock, which are placed upon or succeed one another in regular order, preserve a definite thickness, and appear under the same or similar circumstances in many distant places. In the interior of the country the same conclusion is to be drawn from examining precipitous hills and deep valleys; and even in the flattest country art supplies the means of investigation which nature has denied. The wells, pits, quarries, and mines, which have been constructed, all display the same general truth, and lead us to conclude that the principles and laws of stratification among rocks is confined to no particular country, but all over the world, in continents or in islands, it is certain and constant, so much so, that deep pits are sunk for coal, and miners undertake extensive levels, in full confidence that no exception to the laws of stratification will affect the result of their enterprises. It is not a speculative truth, but a practical law of nature, having the most extensive influence in the whole theory of geology.

So many important facts respecting stratified rocks bear upon the physical history of a county or district, that it is not easy to analyse or realise them on paper in the exact order of their occurrence. But

every student attentive to the subject cannot fail to discover, even in a very limited district, that the different strata which appear above one another are arranged in a certain constant order of succession. A stratum which in any one situation is found beneath another will never, in any other situation, be found above it; in other words, their order is never inverted unless the whole series has been turned upside down.

Superposition of Strata.—As sometimes we neglect to bind in some book a particular leaf, so Nature sometimes omits a particular rock; but she never misplaces them. Most stratified rocks, when exposed in a sea cliff, quarry face, or river bank, are seen to be composed of a number of parallel planes, or layers, or flat tabular masses which more or less readily separate from each other. These strata or beds, whether composed of sandstone, limestone, or clays, are superposed one upon the other, and are classed under the group of rocks which are bedded or superposed one upon the other. These beds are never misplaced, whatever omission or non-deposition may have taken place; and observation has determined that *strata are arranged with respect to one another in a certain constant order of succession.* Strata vary in thickness from fractions of an inch to many feet in thickness, whereas laminæ seldom occur an inch in thickness, varying from this to the thinness of paper.

Inclination of Strata.—Pursuing our investigation, we find that the strata are generally so disposed that their planes of bedding or broad surfaces of junction with each other are not exactly level or parallel to the earth's spherical surface, but slope in some one direction, so as, in that direction, to sink deeper and still deeper into the earth, and to be covered by other strata. This slope, or deviation from the horizontal position, is called the dip or inclination of the strata; and the rocks are accordingly said to *dip* or *incline* to this or that part of the horizon or point of the compass. Dip is the key to the structure of a country, because it acquaints us with the relative antiquity and lie of the beds. It is estimated in degrees, but two observations are generally required to find the direction and amount of the dip. Thus in one side of the figure the beds appear highly inclined. and in the other side but slightly inclined.

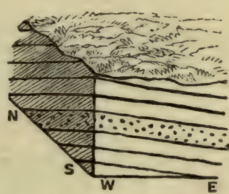


Fig. 15.

On one side the dip appears to be to the north, on the other side to the east. From these observations the true dip is seen to be NNE. Dip may be at any angle, but if the angle is more than 90° the beds are overturned, and the dip is said to be reversed. Thus owing to folding, the order of the beds on the two sides of the section is re-

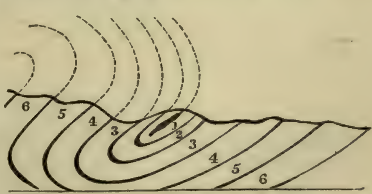


Fig. 16.

versed. Horizontal beds necessarily have no dip. Dip is a property of an inclined plane which causes the plane of a stratum to intersect the plane of the horizon.

The angle of dip is locally often due to the solidity and resistance to flexure of thick deposits. But the direction of dip of one deposit usually governs that of the beds above and below. Changes in the direction of dip are due to the ways in which the strata are folded. In the mountains of Wales the dip constantly changes; and therefore dip enables us to discover the crumpling and folds of the earth's crust. East of the Pennine chain the rocks all dip to the east; and west of that range there is in much of the country a corresponding dip to the west. Dip, no matter how simple it may appear in a single section, is always a part of a fold of the earth's crust. These folds are either downward and trough-like, or upward and ridge-like, though the rocks themselves often appear on the surface in forms which may suggest to the eye neither one nor the other. Thus the chalk of the Chiltern Hills dips to the south-east, and passing under the ground reappears in the North Downs which dip to the north. Hence the chalk has there a basin or trough-shaped fold, and this complex dip is termed a synclinal dip. Whenever a stratum is inclined in two opposite directions so that the dips converge or meet downward, it is synclinal. Almost every coalfield exhibits synclinal dip, because a synclinal fold by sinking the strata below the general level preserves them from destruction. Mountains often have a synclinal structure.

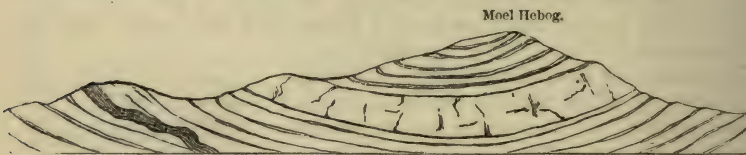


Fig. 17.—Synclinal Dip of the Bala Rocks in Moel Hebog, near Bedgellert, North Wales.

Similarly, whenever a stratum is inclined in two opposite directions so that the dips converge upward, the inclination is termed anticlinal. This is well seen in the mountain limestone of Derbyshire, in the Mendips, and in the Wealden district of Kent, Surrey, and Sussex. The anticlinal of Woolhope is a locality where the succession of the silurian rocks is shown.

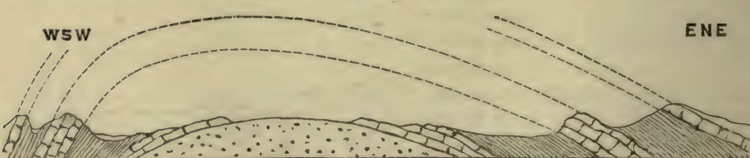


Fig. 18.—Anticlinal Dip of the Silurian Rocks in the Valley of Woolhope.

Thus it is manifest that where the dip is synclinal the newest beds are in the centre of the fold, while where the dip is anticlinal

the oldest rocks occupy that position. Where these dips are repeated frequently in a short distance the deposits are said to be contorted. Contortions of the Carboniferous rocks are well seen in the cliffs near Clovelly in North Devon.

The different rocks which compose the interior of the earth to a considerable depth, therefore, in consequence of this inclination, crop out, or are exhibited in succession on the surface; and hence it is that we are furnished with a vast variety of mineral productions which otherwise would be deeply seated or hidden, and are able to predict the nature of the beds which occur in succession beneath our feet.

Continuity of Strata.—Any one thus far initiated will be able to construct a section or scale of the strata which occur in his own neighbourhood, naming them in the exact order of their succession or superposition, and thus will be furnished with the means of comparing his own district with others near and distant. The results of this comparison are very important, for we thus learn that one general order of succession is observed among all the stratified rocks of England. Certain strata are locally deficient, but all those which do occur together are found invariably in the same relative position. The series of stratified rocks in the North of England, taken in a general way, is expressed by the following names:—Chalk, Speeton Clay, Kimmeridge Clay, Coralline Oolite and Calcareous Grit, Oxford Clay and Kelloway rock, Cornbrash and Oolite rocks, Lias shales, Red Marl and Sandstone, Magnesian Limestone, Coal series, Carboniferous Limestone, and Slate. The series in the southern parts of England is precisely accordant, except that the magnesian limestone is there nearly deficient, that the Kimmeridge Clay is covered by some strata which do not pass the river Humber, and the Speeton Clay is replaced by the Neocomian Sands. Besides, we find the strata of the north of England actually connected by mutual extension with those of the same names in the south of England, so that we thus prove their continuity over large tracts, as well as the constancy of the order of their succession. Every student should trace one or two formations through the country at an early stage in his work.

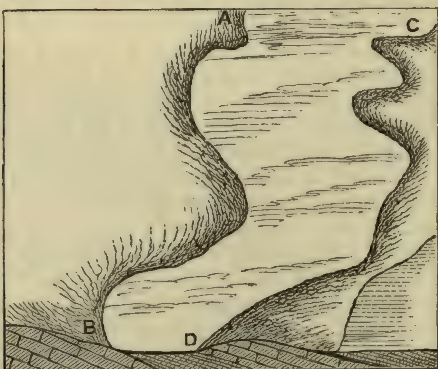
By means of these comparative observations, begun by Mr. W. Smith in 1790, and continued with unabated zeal by others, the whole series of English stratified rocks has been ascertained, and arranged in tabular order; and the geologists of England have, in consequence of the completeness, development, and succession of strata, furnished to the rest of the world a standard of comparison, by which to determine how far the laws of stratification disclosed in this island are applicable to other countries.

Strike.—The direction in which the plane of a stratum extends through a country is termed its strike. This direction is the intersection of the plane of a stratum with the plane of the horizon, and is a property of an inclined plane which is determined exclusively by the direction of dip. The direction of the strike is therefore always at right angles to the direction of the dip. Thus if the dip is to the *north or south*, the strike must be *east and west*. The direc-

tion in which the plane of the stratum extends will therefore change only with the direction of upheaval of the beds, or the lines along which they are folded, so as to be brought to the denuded surface. Thus in the Lincolnshire Wolds the strike of the Chalk is south-east, in the Chiltern Hills it is south-west, in the North Downs it is east and west. But the strike is entirely independent of the contour or elevation of the ground, and equally independent of the direction along which the edge of a stratum can be followed over the surface of the ground, for that direction may vary with denudation, but no amount of denudation can affect the direction in which the plane of a stratum is inclined.

Outcrop.—The area occupied by a stratum on the surface of a country is termed its outcrop. The line of outcrop or basset is the line where the bed comes to the surface from beneath an overlying deposit. The line of outcrop of an inferior bed is the denudation line, or limit of the outcrop of the stratum which rests upon it. In level country the outcrop usually runs straight, but every hill and valley, every variation in the texture of the stratum tends to make its direction variable and sinuous, because outcrop lines are determined by the ways in which the overlying strata are removed by the action of frost, rain, and the sea, so as to uncover the layers beneath. The general direction of outcrop follows the direction of strike, but the details are the consequences of denudation. The nature of the outcrop may be influenced by the mineral character of the deposit. Thus since clays are easily worn away, they form valleys or low level plains. But limestones and sandstones being more durable, often form terraces or ridges of hills which extend in the direction of the outcrop. When a stratum in this way rises up like a sloping cliff, and exposes a large part of the thickness of a stratum along the limiting line of outcrop, such exposure is called an *escarpment*. These exposures, which often resemble inland cliffs, have a base-line which varies in level, and is therefore regarded as having been determined by frost and rain rather than by the sea.

Map.



Section.

Fig. 19.—Map showing lines of Outcrop. A B; C D.

Two modifications of outcrop called "outlier" and "inlier" often occur. An *outlier* is a portion of a stratum which has become separated from the principal mass by denudation, and remains isolated like an island.

In this section (fig. 20) a few hills to the north of London are shown. capped with Bagshot Sand, which alone exist as evidence of a continuous stratum, which has been denuded from the surrounding country.

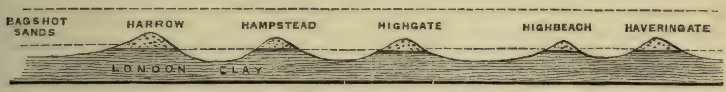


Fig. 20.

Over the chalk of Hertfordshire are scattered numerous outliers of the Woolwich and Reading beds of the London basin, giving some idea of the former great extension of that deposit.

Outliers are frequently widely separated from the principal mass with which they are connected. Thus an outlier of the Lias in Cheshire finds the nearest mass with which it could have been con-

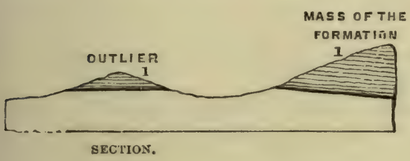


Fig. 21.—Section of Outlier.

Fig. 22.—Map of Outlier.

tinuous in Leicestershire; and other Lias outliers in Belfast, and the valley of the Eden, have the regular formation nearest to them at Whitby. An outlier is always newer than the formation around it.

An *inlier* is an older deposit which is exposed by the removal of a portion of an overlying stratum, so that it lies within a girdle of the surface rock. The most considerable inliers in this country are

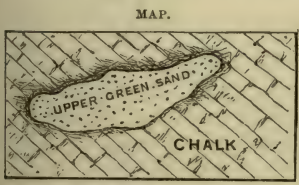


Fig. 23.—Map of an Inlier.

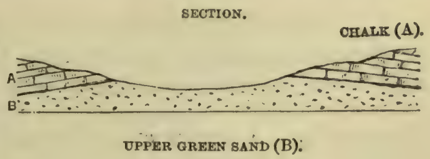


Fig. 24.—Section of Inlier.

the Carboniferous Limestone of Derbyshire, which lies within the Millstone Grit; and the Wealden beds of Kent and Sussex, which are surrounded by the Cretaceous strata. At Woolhope there is a Silurian inlier rising through the Old Red Sandstone, and at the Wren's Nest near Dudley, another Silurian inlier rising through the Coal. Some of the simplest are seen at Inkpen and Kingsclere, where the Chalk is cut through to expose the Upper Greensand beneath.

Stratification a General Principle.—Considerable labour remains

to be accomplished before even the stratified rocks of Europe can be completely compared with those of England, and the want of evidence is still more severely felt with respect to other quarters of the globe. Nevertheless, the following important general results may be regarded as certain. The *principle of stratification* is found to be *universal;* that is to say, in every country of sufficient extent, various rocks are found to be superimposed on one another in a certain settled order of succession, and these rocks are not found only in isolated patches, but often hold their course across provinces and kingdoms.

Throughout the whole area of Europe, from the Ural Mountains to the Atlantic, and from Lapland to the Mediterranean, the stratified masses, taken in their generalities, are arranged upon the same principles, follow one another in the same exact order of succession, and, in fact, form parts of one vast system of rocks, once more perfectly connected than at present.

What is known of the geology of North Africa, Egypt, Syria, the countries bordering on the Caspian, Siberia, and Hindustan, leads to a confident belief that the same general system, modified by local circumstances, will be found also applicable to the greater portion of the surface of the Old Continent.

Analogy of Distant Deposits.—Important agreements between the strata of North America, India, Australia, &c., and those of Europe, have been clearly determined, and the time will probably arrive, when, though it cannot be proved that similar rocks were at the same time deposited in every part of the bed of an ancient sea, at least it will be possible to show, that the same system of natural processes was everywhere in progress, contemporaneously or successively producing analogous effects; thus exhibiting in chronological order, through the relative antiquity and accompanying circumstances of even the most distant deposits, a history of all the varied operations by which in regular gradation our globe has arrived at its present state.

Distinction of Stratified and Unstratified Rocks.

Relative Situation.—Stratification is, therefore, the most general condition or mode of arrangement of the rocks; and in the wide plains and gently undulated portions of the surface, it is often the only one discoverable. A person of good discernment, who should pass his whole life in investigating the south-eastern part of England, or the northern part of France, might conclude, from every observation he could there make, that the external materials of the earth were *universally* stratified, this arising from the fact that no unstratified masses, igneous or otherwise, occur in these areas.

On the other hand, the inhabitant of the mountains sees so many examples of granitic and other rocks, totally devoid of any appearance of stratification, and sometimes finds that structure in the slate rocks so dubious and inconclusive, that he is wholly unable to comprehend the magnificent chain of inductions derived from the study of stratified rocks. Unstratified rocks generally abound along mountain chains and

groups, and very often form their axis or nucleus. Stratified rocks fill the plains and form the encircling flanks of the mountains. When a vast mass of unstratified rock, as granite, forms the nucleus of a mountain group, the stratified materials which surround it generally slope away on all sides, as if the granite had been protruded from below these strata, and, during the act of its uplifting, had broken them and caused them to assume their several inclinations. Other unstratified rocks, as basalt and porphyry, appear amongst the stratified and bedded rocks, sometimes in irregularly lenticular masses, as if they had been spread in a melted state around a common centre, sometimes filling long vertical fissures in the strata, as if they had been injected from below.

Mineral Characters.—On comparing together the stratified and unstratified rocks, we find their mineralogical composition extremely different. The *stratified rocks* are earthy aggregates, as sandstones, clays, or limestones; such materials, in fact, as we know to be accumulated in the same mode of arrangement by modern waters; and in a majority of cases we shall find that most if not all of the stratified rocks are non-crystalline.

The *unstratified rocks,* on the other hand, are generally and evidently crystallised masses, often analogous to igneous or volcanic products, or compounds containing essentially minerals which are not known to be producible from water, but in several instances are obtainable by artificial heat, or generated in the deep furnaces of which volcanic mountains are the vents; and the greater number of the crystalline rocks are unstratified or have no true bedded structure. These generalisations will have their exceptions, some rocks being bedded and crystalline as well, their crystalline nature or condition having been subsequently induced, or they were originally non-crystalline.

Stratified rocks have evidently been deposited successively from above; the lowest first, the uppermost last, in obedience to the laws of deposition.

Unstratified rocks, on the other hand, seem to be derived from below or at depths in the earth's interior, and to have been ejected or uplifted from below the superincumbent strata, as volcanic matter is protruded at the present day, or they may have occurred as lava-flows, or as volcanic ashes, terrestrial in origin.

Contents.—Stratified rocks contain very generally the remains of plants and animals which were in existence at the period when the rocks were deposited or accumulated, exactly as remains of the present races of plants and animals are found buried in the modern deposits formed in water. All such remains are termed fossils, hence the stratified rocks are termed fossiliferous and the unstratified rocks unfossiliferous, and in nearly every instance a non-crystalline rock is fossiliferous.

But unstratified rocks contain no such evidences of aqueous origin or mechanical aggregation, and they rarely possess organic remains except when volcanic ashes or mud have entombed the life of the time.

Petrological investigations lead us to arrange the rock masses of the globe into these two classes:—

1st Class.	*2d Class.*
Crystalline.	Non-crystalline
Unstratified.	Stratified.
Unfossiliferous.	Fossiliferous.

Origin.—By all these characters, separately and comparatively considered, the two great divisions of materials which compose the external parts of our globe are proved to have been produced by entirely opposite causes. Stratified rocks are analogous to the modern products of water, and were therefore called by the older authors Neptunian, while unstratified rocks are analogous to the modern products of volcanoes, and receive the names of Plutonic and Volcanic, according to the conditions under which they cooled.

Mode of Study.—The distinction now insisted upon between rocks of deposition and rocks of eruption or non-crystalline and crystalline rocks, is of the highest importance, and requires the closest attention at the very commencement of the study of geology. For not only are these different classes of rocks distinguished by most important general characters, but even the methods by which they are to be investigated, and the preliminary knowledge required for this purpose, are entirely distinct. Amongst the stratified rocks a knowledge of zoology and botany or biology is required to understand and develop the past history of the remains of plants and animals, which were buried at successive periods; on the contrary, among the mountains associated with granite and metamorphic rocks, where minerals of every hue and form appear in ever-different combination, scientific mineralogy is of much higher importance, and study of slices of rock under the microscope is often necessary.

In consequence, geology divides itself into two branches—one, Biological, which links itself with the natural history of modern plants and animals; and the other, Physical, closely connected with chemistry and natural philosophy. And we have now, and have always had, two distinct groups of geologists, whose progress and discoveries have been as different as the preliminary knowledge which their different spheres of research required.

A geologist of adequate attainments must now indeed be acquainted, at least generally, with both branches of this wide subject; and therefore he who is unacquainted with either mineralogy on the one hand, or zoology and botany on the other, must be considered as only half-prepared for original investigation. He must be further instructed in palæontology and physical science before he can be sent to explore an unknown region, or permitted to give an opinion on the whole theory of geology.

As much practical knowledge, therefore, as can be easily gained of the minerals which enter most frequently into the composition of rocks and veins, and of the natural history of the plants and animals whose remains lie buried in the strata, is absolutely necessary to the student's progress in this science.

On Stratification in general.

Strata, the term defined.—*Strata, layers, and beds are synonymous terms.* "Strata," says Professor Playfair, "can only be formed by seams which are parallel throughout the entire mass." This definition was founded upon the supposition that loose materials deposited under water must be arranged in layers parallel to the surface of the water; it undoubtedly contains the general or fundamental idea of stratification, but is often too abstract for practice. It includes too much, for slaty cleavage produces truly parallel laminæ; and it excludes many layers produced under greatly agitated water, on lines of sea-coast, and in the direction of sea-currents, such as conglomerates, false bedding, &c. The most remarkably regular and parallel seams or divisions between strata happen in calcareous and argillaceous rocks; but the partings in sandstone are much less uniform. A particular shelly bed of stone lies at the top of the coralline oolite of Yorkshire, and may be traced for a great distance; a red rock, long since noticed by Lister, lies at the base of the chalk of Yorkshire and Lincolnshire, and cut through by the Wash, reappears in the same position in Norfolk, for sixty miles in compass; the cornbrash limestone, seldom more than ten feet in thickness, is continuous from Dorsetshire nearly to the Humber, and reappears in the cliffs at Scarborough. In these instances, therefore, Playfair's definition applies very well. On the contrary, the beds of sandstone with coal which are interposed in the Lower Oolite system of Yorkshire, are altogether five hundred feet thick near Robin Hood's Bay, but dwindle toward the south, and are entirely deficient before reaching the Derwent.

Such beds are therefore wedge-shaped; and cases sometimes occur, as in the Lincolnshire limestone, where, by attenuation in all directions from the centre, they become lenticular. See fig. 25 for these and other appearances.

Interposed Strata.—The strata, therefore, are not all co-extensive. Limestones and thick clays are probably the most persistent and regular, sandstones the most limited and local. *Local modifications* or *interposed beds*, due to conditions of the sea-bed, cause the principal differences between distant portions of the same formation.

The Lias of England rests immediately upon red and bluish marly clays with white gypsum; at Luxembourg these strata are separated by a thick sandstone. In the north of England, Magnesian Limestone separates the Coal Measures from the New Red Sandstone; but in other parts of the island these two formations are in contact. In the breast of Ingleborough, the limestone beds are aggregated into one vast mural precipice or scar; but as we proceed northwards, this mass opens and

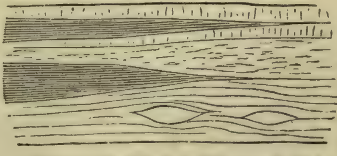


Fig. 25.—Lenticular, Interposed, and Divided Beds.

subdivides to admit layers of sandstone, shale, and coal, which gradually increase under Crossfell, and swell out to a vast thickness in Northumberland, so as to contain several valuable seams of coal, thick masses of sandstone, and abundance of shale, between the horizontally separated beds of limestone.

The Oolitic strata, near Bath, are composed of two portions—the Upper or Great Oolite, and the Inferior Oolite—and between them is a series of calcareous and argillaceous beds called Fuller's Earth, sometimes one hundred and fifty feet thick. As we proceed northward into Lincolnshire, the Fuller's Earth beds die away, thin out, or are excluded from the series; still farther north the whole series is changed; so that in Yorkshire it includes thick layers of sandstone, shale, and coal. On a first view the districts of Bath and Yorkshire are very unlike, but the contemporanity of their deposition is certain from the continuation of the same Oolitic beds and organic remains through both of them.

Thickness.—The *thickness* of the beds or strata varies exceedingly, and seems to have reference to the rapidity, regularity, and continuity of the deposition, and the rate of consolidation of the materials.

The Chalk is commonly about five hundred feet thick, and in all this great mass we can scarcely trace any decided beds; though the layers of flint at equal distances, and the difference of the organic remains at different depths, evidently prove a succession of stratified deposits.

The Great Oolite near Bath is, on the contrary, divided into *a certain number* of beds, definite in quality, thickness, and order of position.

Laminæ.—A stratified rock, therefore, is composed of one or more layers of strata, but this is by no means the last term of the analysis. Each bed is often composed of many laminæ, which are

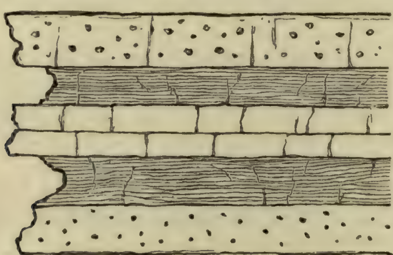


Fig. 26.

sometimes parallel to the plane of the bed itself, and sometimes lie in it at different angles. Thus micaceous laminated sandstones, and in particular the best flagstones of the coal districts, are composed of a multitude of thin layers parallel to the plane of the bed, and entirely covered by plates of mica, which probably cause the splitting of the stone. This appearance is very analogous to the laminated sand quietly left by the successive floods of a river.

False Bedding.—But the coarser flagstones of the same coal districts are often composed of laminæ, laid at various angles to the plane of the bed, and in consequence producing a rough, uneven, shattery surface, and a tendency to oblique fractures.

Such appearances of oblique lamination are occasionally found in the modern sediment of agitated waters, both in the banks of rivers, in estuaries, and on the sea-shore.

When these oblique laminæ extend through thick beds, they sometimes cause a slight difficulty in determining the dip of the strata, and are then called *false bedding*. Some of the coarse upper beds of the Great Oolite of Bath, Gloucestershire, Northamptonshire, and Lincolnshire, as well as of Normandy, are remarkable for this false bedding.

But it is in the coarse sandstones that we see the most remarkable examples of this structure, as in the Oolitic sandstones, &c., on the coast at Scarborough, and in the Trias rocks under Nottingham Castle, and it is generally seen in valley gravels. False bedding, oblique lamination, or current bedding, is indeed one of the most characteristic features of shallow-water deposits, and is never observed in clays. It is due to changes in the directions of the currents which accumulated the deposit, and we can often discover from the inclination of the laminæ the directions from which the current flowed which formed each of the successive beds.

In this diagram the layers 1 and 2 in the face of the section might be supposed to be regularly bedded and upheaved, for colour accumulates in the laminæ and is often washed out of the planes of stratification, but a glance at the other side of the section shows at once that we have a case of current bedding. Bed 1 is seen by the compass points to have been formed by a current flowing from the east; then the current changed, and flowing from the north-east cut off the tops of the first set of laminæ, and threw down bed 2. In bed 3 the current comes from the north.

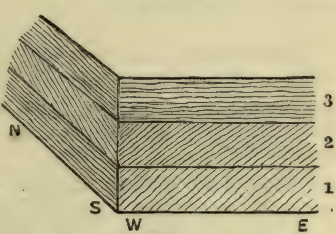


Fig. 27.

The more violent the action of the water, the less regular is the internal constitution of the layers found beneath it. Let any one with this view compare the effects of the tide beating upon the sand and pebbles of the eastern coast, or the tumultuous products of a mountain river, with the tranquil deposit and sediment on the alluvial lands near Lynn and near Hull. In the former case the materials are frequently found heaped together in laminæ, variously and confusedly inclined to one another; in the latter they are all parallel to the horizon, and to the general plane of the surface. The former case, the shore lamination, is analogous to the false bedding mentioned in a preceding section, so general in our sandstones and conglomerates, and in shelly beds of Oolite; the latter is exactly like the regular lamination of clays and shales. Like effects flow from like causes, and thus we

are enabled to frame very plausible conjectures concerning the condition of the waters under which the several strata were accumulated.

General Terms.—In the same way as a number of similar laminæ are sometimes united into one bed of stone, so several similar beds of stone are sometimes associated into one rock, to which a specific name is applied, as the Oolite, the Lias limestone, &c.

Sometimes several of these rocks are grouped under the title *formation*, as the Bath Oolite formation. Thus the Lias limestone beds, the Lower Lias clay, Marlstone beds, and Upper Lias clay, are all included in the Lias *formation*, which rests upon the New Red Sandstone *formation*, and is covered by the Bath Oolite *formation.*

The International Geological Congress has recommended that the largest series of Geological Deposits, such as Primary or Secondary, should be termed a Group; the Group should be divided into Systems, such as Cambrian System, Silurian System, &c.; the System is to consist of Series; the Series is made up of Stages; and each Stage may be resolved into Beds. These terms have corresponding names to indicate divisions of time; thus—

Sedimentary Terms.	*Chronological Terms.*
Group,	Era,
System,	Period,
Series,	Epoch,
Stage.	Age.

From these names the familiar English term Formation is omitted, because it has been used on the Continent to indicate the mode of accumulation of a deposit, instead of the deposit itself; but it may be long before English writers entirely give up this equivalent for the term Series.

Groups of British Strata.—The whole series of British strata are grouped, according to their relative antiquity, into three leading divisions—the Primary, or Palæozoic; Secondary, or Mesozoic; and Tertiary, or Cainozoic strata; it being understood that such divisions are chiefly adopted for convenience, as expressing with considerable accuracy certain general analogies of origin, composition, and organic contents, which prevail amongst the members of each division, but yet are not to be considered as exclusively belonging to them.

Two of these three divisions are again subdivided, upon exactly the same principles, into systems of strata, which are marked by certain recurrent rocks, striking analogies of composition, organic remains of similar types, and positions derived from convulsions of the same geological epoch.

The systems are again usefully divided into formations or series; these into their several component stages or rocks; whose ultimate analysis gives the strata, beds, and laminæ of composition. The superficial accumulations of gravel, sand, peat, &c., are classed under the head of alluvial deposits.

The Tertiary or Cainozoic Group of Strata are partly lacustrine,

but principally marine, sandy, and argillaceous, and with some calcareous deposits, abounding in shells and other organic exuviæ, closely analogous to existing species.

Secondary or Mesozoic Group of Strata are principally of marine origin, with rare and local estuary deposits; consisting of repeated alternations of limestone, flint, sandstone, sand, clay, iron ore, coals, salt, &c., with organic remains, generally very distinct from existing forms of animals and plants.

Primary or Palæozoic and Hypozoic Strata.—The Palæozoic rocks contain organic remains, mostly of marine tribes, and the species are all extinct.

Disturbed Stratification.

Strata originally Level.—All strata, says Cuvier, in his admirable "Discourse on the Revolutions of the Globe," must necessarily have been formed horizontally; and this opinion, founded upon the admission that rocks composed of regular layers, containing rounded pebbles and organic remains of water-animals, can only have been formed under water, is supported by observation. For not only do we see at the present day the deposits from water arranged in planes nearly or exactly horizontal, but we also find the ancient strata of the earth, where undisturbed by convulsions, very nearly level. In consequence of these disturbances the strata are seldom found to be perfectly horizontal, but are often inclined at high angles, and in a few instances stand directly vertical. Their planes are generally continuous over large spaces, but they are sometimes broken and dislocated by *faults* or *dykes.* It is now generally admitted that the usual horizontal disposition of the strata is derived from the action of the supernatant waters which accumulated them; and that the irregular declinations and fractures which we sometimes behold are the effects of subterranean convulsions or changes chiefly occasioned by internal contraction. All strata which were deposited in continuous sequence so as to rest evenly upon each other are said to be *conformable*, and the succession is termed conformity. These show no evidence of changes affecting the general directions of the coast lines, or form of the sea-bed at the time of their deposition. There is no evidence of destruction of the beds previously formed, and the interval of time between the beds was probably short

Subsequently Disturbed.—Earthy matter deposited from water by tranquil subsidence, as clay and limestone, or accumulated during periods of moderate agitation, as sand and sandstone, must in general be arranged into layers or strata, proportioned to the intervals of deposition; and these layers, in consequence of the fluctuation of the water and the influence of gravitation, will especially tend to be horizontal. Nevertheless they must, in a considerable degree, accommodate themselves to the surface on which they are deposited. If the bottom be level, so will be the deposit; if sloping, the deposit will be inclined; but if there be a perpendicular subaqueous cliff, no deposit can fall

upon its face, nor any transported materials be accumulated parallel to it. An originally perpendicular layer or deposit of earthy materials is obviously impossible. Whenever, therefore, we behold vertical strata, we may be quite sure that they were not deposited in that form, but have been displaced by some internal movements of the earth.

Vertical Strata.—Abundance of instances of this position of strata may be quoted in almost any part of the world. The Isle of Wight gives us, in Alum Bay and Whitecliff Bay, a magnificent series of strata, 1100 feet in thickness, reared into an absolutely vertical position; and this effect is the more remarkable, because the materials uplifted consist of many strata of loose sands and pebbles, which most certainly have been deposited nearly level. Similar phenomena are seen in the Isle of Purbeck. In the western borders of Yorkshire, vertical strata of limestone range for miles parallel to the edge of the Pennine chain, and turn eastward through Craven, below Ingleborough and Pennyghent, to Settle. Magnificent examples of vertical strata are familiar to those who have visited the mountains of Savoy, or who have read the graphic descriptions of Saussure.

Contorted Strata.—There are some remarkable instances of contorted stratification very difficult to be explained without supposing the strata to have been soft at the time of the flexure. Not to dwell on inferior examples, we shall quote the magnificent phenomena of this kind which are seen in the valleys of Chamouni and Lauterbrunnen, along the shores of the Lake of Lucerne near Fluellen, and the schistoze rocks of the stack in Anglesea. The stratified limestones and other rocks of these localities are bent with such extraordinary retroflexions, as to imply repeated or continuous operations of the most violent mechanical agency, producing displacements in different directions; and observations along the range of the Alps prove that the whole of this chain has been the theatre of enormous and reiterated convulsions, such as might be anticipated from the amount of compression which must have been necessary to uplift that mountain chain.

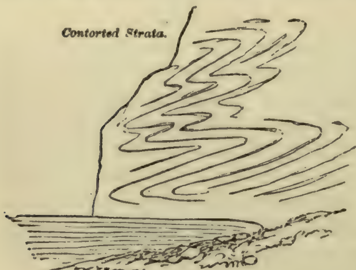


Fig. 28.

Faults.—But the most singular case of disturbance is when strata, either horizontal or inclined, being too rigid to bend under flexure, break, and are displaced, so that on one side of the line of fracture the corresponding rocks are much higher than on the other. This difference of level in places sometimes amounts to hundreds or even thousands of yards. The succession of strata is on each side the same, their thickness and qualities are the same, and it seems impossible to doubt that they were once connected in continuous planes, and have been forcibly and violently broken asunder.

The plane of separation between the elevated and depressed portions of the strata is sometimes vertical, but generally sloping a little. The direction of inclination of the plane of a fault is termed its *hade*. In this case a peculiar general relation is observed between the inclination of this plane and the effect of the dislocation. In fig. 29, for instance, the plane of separation, *z z*, slopes under the depressed, and over the elevated portions of the disrupted strata, making the alternate outer angles *z z b*, *z′ z′ b′ acute*. In several hundred examples of such dislocations which have come under notice an exception to this rule is rarely found. The direction of the hade is almost invariably *towards the downthrow*. A similar law is found to prevail very generally in the crossing of nearly vertical mineral veins; for instance, in fig. 30, *a a* are two portions of a metallic vein, dislocated by another

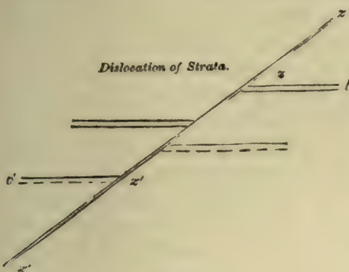


Fig. 29.

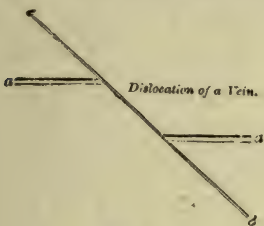


Fig. 30.

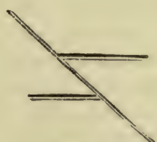


Fig. 31.

vein, *b b*. In this case the relation of the line *b b* to the lines *a a*, is the same as that of *z z′* to the lines *b b′*, &c. The contrary appearances, had they occurred, would have been as represented in fig. 31, and such occur in the mining district of Cornwall; they are termed upthrow or reversed faults. When faults are parallel to each other, and the throw is always in the same direction, the strata descend like steps, and the faults are called step faults. When faults cross each other they produce the phenomena termed trough faults or cross faults.

The line in which a fault extends is always sinuous, and owing to displacement faults always include many pockets in which minerals may accumulate.

The line of dislocation is generally distinguished by a fissure which is filled by fragments of the neighbouring rocks or by basalt, and then is called a *dyke*, or by various sparry and metallic minerals, and is then called a *mineral vein*. The faulted surfaces which have been compressed against each other are hardened, striated, and often polished, when they are termed slickensides.

There is every reason to suppose that many faults are produced slowly, when land is being upheaved, since the rocks which were left elevated on one side of the displacement are invariably cut level by marine denudation. Faults often modify the outcrop of strata owing to this circumstance. Thus, in South Lancashire, a coalfield is divided by a fault; and since it was in the form of a basin, the part which was thrown down shows on the surface as a large curve, while, the other part owing to denudation remains as only the bottom of the basin, and the curve is proportionately small. Some faults affect the rocks very slightly and over a small area; others, like the Craven fault, have a downthrow of a thousand yards, and may be traced for seventy miles.

Relative Age of the Dislocation.—The irregular operations by which these disturbances and dislocations were occasioned seem to have happened at various periods during the formation of the strata. We know, for instance, examples of horizontal strata, as in figure 32, resting upon other highly inclined strata, which must have been forced into their unnatural position before the deposit of the level strata upon them.

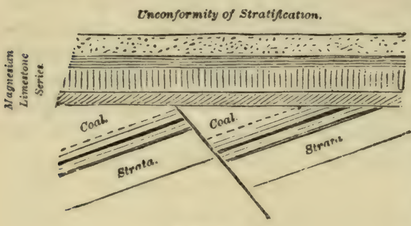


Fig. 32.

Such a case occurs in Somersetshire, where the Coal Measures lie at a steep slope beneath horizontal beds of red marl. These Coal Measures are also greatly broken by *faults*, which in some cases throw or elevate the beds on one side more than seventy fathoms above those on the other side. But the beds of red marl above are altogether uninfluenced either by the steepness of the dip or the abruptness of the dislocations. Therefore, the convulsions by which the effects were occasioned which are shown in the section happened after the deposit of the coal seams and before the deposit of the red marl.

At Aberford in Yorkshire, and at many other points along the line of the magnesian limestone between Nottingham and Sunderland, similar examples occur. At Vallais Bottom, near Frome, the mountain limestone is found highly inclined, below level beds of oolite; and the mollusca (*Lithodomi*) which lived in the oolitic sea have bored holes into the subjacent limestone.

In such cases the discordance of inclination between the superior and inferior strata is expressed by the term *unconformity*, and the upper rock is said to lie *unconformably* upon the lower. Unconformity always implies an unrepresented interval of time, during which (1) the sea-bed was inclined at a new angle, and (2) the previously formed deposits now upheaved were denuded so as to form a new horizontal surface on which the succeeding or unconformable deposit was accumulated.

Overlap.—Strata are sometimes conformable in one section, and yet when traced to a distance are found to be unconformable to the

deposits on which they there rest. This condition is termed overlap, or transgression, because the overlying deposit extending beyond the beds previously deposited overlaps and covers them up. Overlap occurs whenever the level of land is depressed over a wide area, so as to allow the sea to extend inland and throw down a stratum upon ground where the series had necessarily been interrupted. A remarkable overlap of the Chalk is seen in Yorkshire, for in the cliffs at Speeton the conformity is perfect; but as the Chalk extends inland it rests successively upon all the Secondary strata down to the Trias. Similarly in Dorsetshire and Wiltshire, the Cretaceous rocks are conformable to the underlying series, but as they extend westward the Upper Greensand rests successively upon all the Secondary strata, till in the Haldon Hills it overlaps Carboniferous rocks.

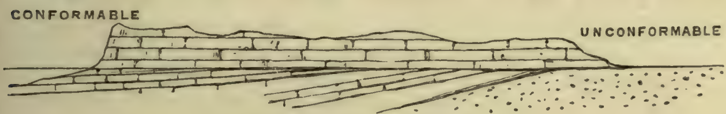


Fig. 33.—Diagram of Overlap.

Principal Epochs of Convulsion.—By pursuing this investigation in different situations, we find that these internal movements or convulsions happened at intervals during the whole period of time occupied in the deposition of the strata. Some of the most prevalent and remarkable cases of dislocation and unconformity are, however, observable: (1) immediately after the deposition of the Cambrian series, between the Upper and Lower Llandovery beds; (2) after the accumulation of the Coal Measures in the Carboniferous system; (3) after the deposition of the oolitic rocks; (4) after the deposition of the Chalk; and (5) one of the most recent probably of all, after the completion of all the regular formations above the Chalk. It is not to be supposed that all even of these principal cases of dislocation can be recognised in every country; on the contrary, the subterranean forces frequently shifted their directions and points of action. There is no difference except in magnitude, and the degree to which it is deep seated between the displacement of surface indicated by an ordinary fault and the submergence or elevation of the largest areas of land.

We shall have occasion to show, while speaking of the organic remains, that there is sometimes observed a singular harmony between these periods of extraordinary internal disturbance and the several epochs when the different races of animals and plants came into existence; and it is not unreasonable to suppose, that in this manner we may find it possible to establish such a relation between physical and organic phenomena as to demonstrate the geological dependence of the distribution and mutations of life upon changes taking place in the earth's physical geography in successive ages.

Proximity of Mountains.—At present, restricting ourselves to the phenomena of elevation and disruption of the strata, we shall carry our inductions one step further, for the purpose of proving what was before

announced, viz., that these disturbances were probably connected with the effects of internal heat.

We shall assume, then, that granitic, and basaltic or trappean rocks, and others exhibiting the same phenomena, were crystallised from a state of igneous fusion, and were, sometimes in a fluid, and sometimes in a solid state, impelled upwards towards the surface of the earth, as analogous substances are now ejected or poured forth as fluids through volcanoes, or lifted in a solid state by earthquakes, &c.

In proportion as we approach the mountains where the greatest violence has been exerted to break up the strata, raise the granite, and inject the basaltic dykes, we find the dislocations increased in number and importance, and the confusion of the stratification more prevalent.

The central nucleus or axis of many mountain districts is a mass, or a series of masses, of granite and other unstratified or metamorphic rocks, from which on all sides the strata are found dipping away at high angles. In such cases there can be seldom room to doubt that the elevation of the mountain ranges and the disturbance of the strata was occasioned by the same violence which uplifted the granite.

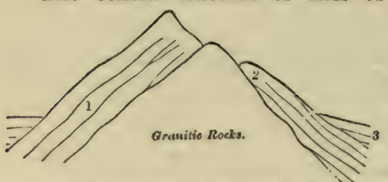


Fig. 34.—1 and 2. Primary Strata. 3. Secondary Strata.

The area of granite disclosed between the opposite slopes of strata is indefinite, sometimes very large, sometimes very small, sometimes it is entirely covered over by the rocks which it has uplifted, but not protruded through or perforated. The general analogy in the composition of mountains, in the strata which surround them, and in the dislocations which abound in their vicinity, prove that one common subterranean force has produced all the phenomena in question.

Basaltic rocks frequently, perhaps generally, show themselves in situations removed from the granitic regions, on the flanks of mountains and often in lower ground. In numerous instances, basalt fills up the fissures between the elevated and depressed portions of dislocated strata, and as it cannot be doubted that such a fissure would soon have been filled up by other substances, it is clear that the melted basalt was injected nearly at the same time as the dislocation was produced; that is, that both were local effects of diminished pressure acting on regions affected by internal heat. How this heat was produced, is a question that will receive consideration subsequently.

Analogy of Mineral Veins and Trap Dykes.—So great a general analogy prevails between some mineral veins and basaltic dykes, that in almost all hypotheses their origin has been assumed to be similar in kind. Both in the same manner divide the strata; in both the materials are crystalline, often such as are not known to be pro-

ducible from water, and arranged according to entirely different laws from those which regulate deposits from cold water. It seems, at first, almost inconceivable that materials of such various specific gravity and chemical affinities should be either soluble at once in heated water or capable of being introduced by this process at different times; but all the circumstances agree in claiming for mineral veins a different origin from basaltic dykes, the igneous origin of which is supported by the strongest possible arguments. We shall, however, discuss the history and nature of mineral veins more at large in a subsequent chapter, and shall then notice phenomena concerning them which can with difficulty be explained in the present state of our knowledge of chemistry.

Exhibition of Useful Minerals.—It is not only in the elevation of continents, the varying height of mountains, the division of the sea, and similar striking effects, that we see the utility of the combination of subterranean igneous with superficial aqueous agency. Every coalfield in the known world proves distinctly the utility of even the minor dislocations, which in our imperfect language are called "faults" in the strata. The universal effect of these "faults" is to multiply the visible edges of the strata, by bringing them more frequently to the surface, in consequence of which there is, in the first place, greater chance of discovering useful minerals; and, secondly, greater facility in working them.

Internal Structure of Rocks.

Joints in Different Rocks.—All rocks, whether stratified or not, are naturally divided by fissures into masses, which are of different forms in dissimilar rocks, and pass in various directions, independent of the strata. The fissures or planes of parting between these masses are called *joints*. Most frequently their direction is nearly at right angles to the planes of stratification or bedding, where such exist, and they divide the rock into cubical, rhomboidal, or prismatic portions, blocks, pillars, or columns. It is owing to their various direction and frequency that different rocks assume such characteristic appearances, and may thus be often and readily distinguished when seen at a distance.

Some rocks have very numerous, approximate, and closed joints, as shale, some kinds of slate, and laminated sandstones; in others, as limestones, the joints are less frequent and more open.

In coarse sandstones they are very irregular, so that quarries of this rock produce blocks of all sizes and forms. From this cause, coarse sandstone rocks show themselves against or facing the sea, in precipitous valleys, or on the brow of hills, in rude and romantic grandeur. The wild scenery of the Peak of Derbyshire, Brimham Crags, and Ingleborough in Yorkshire, derive attractive features from the enormous blocks of Millstone Grit; and the magnificent rocks which stand upon the hills and overlook the Vale of Wye, are composed of a somewhat similar material.

In clay, vertical joints are numerous, but small and confused, whereas in indurated shale they are of extraordinary length, very straight, and parallel, dividing the rock into rhomboidal masses. This may be well studied in the shale, which alternates with mountain limestone, at Aldstone Moor in Cumberland. Rhomboidal joints are frequent and very regular in coal.

In limestone the vertical joints are generally regular, and arranged in two sets, which cross at nearly equal distances, and split the beds into equal-sized cuboidal blocks; and thus the mountain limestone is found to be divided into vast pillars which range in long perpendicular scars down the mining dales of the north of England.

All water-formed rocks, after being upheaved, dry and shrink. The superficial beds in any quarry may be seen to be divided more perfectly and into smaller pieces than the masses which are deeper-seated and moist. This shrinkage is not merely lateral, but to some extent vertical also, and these shrinkage planes are the beginnings of joints. Afterwards, when the strata became strained and bent during the changes of level in land, these planes became extended and systematised in definite and parallel directions.

In slate districts, the joints, more numerous and more regular than in any other known rock, have almost universally a tendency to intersect one another at acute and obtuse angles, and thus to dissect whole mountains into a multitude of angular solids, with rhomboidal or triangular faces, which strongly impress upon the beholder the notion of an imperfect crystallisation, produced in these argillaceous rocks since their deposition and consolidation by some agency, such as heat or pressure, capable of partially or wholly obliterating the original marks of stratification; but we may with more probability here also appeal to tension in successively different directions as the true cause of these phenomena.

Vertical joints are frequent in granite and appear to have definite directions. The trihedral and polyhedral vertical prisms of basalt, and some other igneous rocks, coupled with their regular transverse divisions, seem to give us the extreme effect of regularity in the division of rocks by the process of condensation, from the state of igneous expansion.

Cause of other Joints and Fissures. — That contraction after partial consolidation of the mass is the general immediate cause of the numerous fissures of rocks, may easily be proved by a variety of facts observed in conglomerates, where pebbles, and in other rocks organic remains, are split by the joints. According to the circumstances of the case, this process has produced in basalt, slate, and coal, fissures so regular as to give to the rock a largely crystalline structure, but left in sandstone mere irregular cracks.

From Mr. Gregory Watt's experiments on fused basalt, and some other notices by different authors, we know that a continued application of even moderate heat to a previously solidified body may be sufficient to develop in it new arrangements of the particles, new crystalline structures, new chemical combinations, and to cause a real transfer of

some of the ingredients from one part of the mass to another. From many independent facts it is inferred, as a matter of certainty, that all the strata have locally, and the lower ones perhaps universally, sustained the action of considerable heat since their first deposition, consequent on folding and pressure: we seem, therefore, to be possessed of the clue which is eventually to conduct us to a knowledge of the cause of the different structures observable in rocks independent of their stratification.

But, though heat be taken as the leading cause of many of these effects, it is by no means inconsistent to suppose that some other independent agent—as, for example, electricity—might be concerned in modifying the result. From discoveries in electricity, it appears certain that this universal agent is excited in every case of disturbance of the chemical or mechanical equilibrium of natural bodies; and it is especially and very sensibly excited by unequal distribution of heat. Professor Sedgwick's suggestion with reference to Mr. Fox's electro-magnetic experiments on the mineral veins of Cornwall, that electricity was probably concerned in the original production of those veins along which it now circulates, may be perhaps extended to the contents of the joints of rocks; in the study of which Professor Phillips found abundant reason to believe that the theory of the production of mineral veins is inseparable from that of the joints and fissures, in some of which the metallic substances are deposited.

The joints in igneous rocks like those in aqueous rocks are due to contraction, but it is contraction on cooling. In granite, the joints are remarkably regular, and generally correspond with the crystalline angles of the mineral orthoclase which constitutes more than half its bulk; so that if any considerable portion of the crystals are arranged in a definite direction in the rock, we might expect the mass on shrinking to divide by joints in planes defined by crystalline structure. This has yet to be proved; but it is probable that nearly all joints in igneous rocks are due to the combined influence of these causes.

Direction of Fissures.—In examining with attention a considerable surface of rock, it will be found that amongst the joints are some more open, regular, and continuous than the others, which occasionally altogether stop the cross-joints, themselves ranging uninterruptedly for some hundreds of yards, or even for greater distances. There may be more than one such set of long joints, and, indeed, this is commonly the case; yet, generally, there is one set more commanding than the others, more regular and determined in its direction, more completely dividing the strata from top to bottom, even through very great thicknesses and through several alternations of rock. For example, there is a peculiar character of joints in each of the principal strata of the mountain limestone series, limestone, sandstone, shale, and also in the sandstones shales and coal of a coal district; yet, throughout the whole of Yorkshire, all these rocks are divided by the *master-joints* passing downward through them all in nearly the same direction, north by west and south by east. These master-joints, called

slines, *backs*, *bords*, &c., are perfectly well known to the workmen, as well as some other very important yet less certain and continuous fissures passing nearly east-north-east and west-south-west. It is according to such joints that the experienced collier arranges his workings, and the slater and quarryman conduct their excavations. Now, surely nothing can be more certain than the inference that some very general and long-continued agency, such as gradual tension or straining, pervading at once the whole mass of these dissimilar and successively deposited strata, was concerned in producing this remarkable constancy of direction in the fissures which divide them all. The deficiency of recorded observations prevents a general development of this important subject by reference to other districts, but it is obvious that a great principle in the construction of the earth is here indicated, which must eventually have an important influence on geological theory. In the meantime, we may remark, *first*, that these prevalent directions of north by west and east-north-east are those of the principal *mineral veins* in the north of England, and that they are also admitted to be very prevalent in the southern and western mining countries as cross-courses; *secondly*, that these directions are wholly uninfluenced either by the *inclination* of the strata or by the numerous *dislocations* to which they are liable. Whatever be the direction of the dip, how frequent soever the faults, the lines of the great joints are the same. These lines are frequently the cause of particular courses in rivers and springs, long scars on mountain-sides, and subterranean channels for water. Faults, and dykes, and mineral veins very frequently pass along them, and there is little doubt that the diligent study of them will be found to throw much light on some of the most interesting phenomena of geology.

Division of Strata by Master Joints.

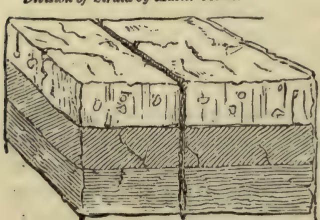


Fig. 35.

Cleavage.—There is yet another structure not common to all rocks, nor confined to a given geological age. Though most frequently manifested among the Primary strata, it is sometimes observable in others of a later date. This structure is called cleavage, and it consists in a peculiar fissility of the rocks which are affected by it, parallel to a certain plane, which almost always cuts at a considerable angle the plane or curved surfaces of the stratification. In fig. 36, which represents a mass of rocks in which this definite quality of splitting is developed, B B is the surface (curved in this instance) of one bed of the stratification; J is on the plane, here supposed vertical, of a joint; C is one of the planes of cleavage, cutting the surface of stratification B B in *s-s*. Parallel to this plane C, the mass of rock here represented is cleavable by art, and is often actually cleft by nature, into very thin and numerous plates, which, when of suitable quality and reduced to proper size, constitute the roofing-slates of our

European houses. The edges of these plates may be traced with care on the vertical surface of the joint J, and the sloping surface of the bed B, and are represented in the figure by fine lines.

It will be observed that these lines do not cross the bed marked *g* (fig. 36). This is supposed to be a hard grit or conglomerate, and such rocks are sometimes only in a slight degree affected by the cleavage, which, however, is perfect above and below them in fine-grained and more argillaceous strata. Certain small joints, however, and numerous cleavage planes, often cross sandstone beds, and then the cleavage and joint planes *in these beds* are not parallel to the general cleavage, but meet the surfaces of stratification, as in this figure, at angles more nearly approaching to a right angle. At *l* the cleavage crosses nodular limestone or ironstone, and in these irregular layers becomes irregular, curved, and confused.

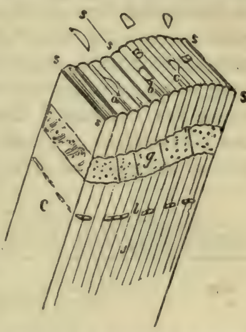


Fig. 36. — Showing that the cleavage does not pass through a bed of sandstone (*g*).

On the surfaces of stratification the cleavage structure is frequently traced in narrow interrupted hollows and ridges; these surfaces have in fact been folded, or plaited, or puckered by the force which occasioned the cleavage; and the little folds thus occasioned are traceable across shells, trilobites, &c., which are thus more or less distorted in figure.

On a careful scrutiny of these shells and trilobites, we find that they have been compressed or elongated *in one direction*, so that a semicircular shell (*Orthis*), whose hinge-line lies parallel to the cleavage edges on B, is found to be altered to the figure *a*; another, whose hinge-line lies across these edges, assumes the shape of *b*; and a third, whose hinge-line is oblique to the edges of cleavage, becomes distorted as *c*. To make this more clear, the letters B B are represented as having undergone the compression in question.

When, as sometimes happens, there are on these surfaces shells and pebbles, too solid and firmly compacted to yield to the cleavage force, *they* are not altered in figure, but the cleavage laminæ in the mass around them are changed a little in direction. Some alteration of direction frequently occurs when the cleavage is passing from one bed to another of a different degree of solidity. And in some tracts of country (*e.g.*, the district of Cork), the cleavage planes commonly are not parallel in contiguous beds, of unlike quality, but appear as in fig. 37. The cleavage plane is most oblique to the bedding in the softest and most argillaceous strata.

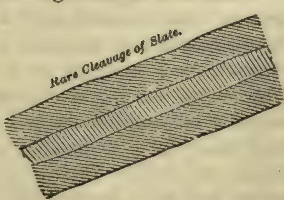


Fig. 37.

One general relation appears between the stratification and the

cleavage—a relation arising from the displacement of the strata by axes of elevation and depression. Parallel to these axes is the "strike" or horizontal line on the surface of the strata; if this be taken on a great scale and the "strike" of the cleavage (similarly defined) be compared with it, the direction of each is found to be the same, or nearly so; in other words, the cleavage edges on the surface of the strata are horizontal lines (*s-s* in fig. 36). The direction, then, of the cleavage in a given district is dependent in a general sense on that of the axes of earth-flexure in that district; but the *inclination* of the cleavage has no necessary known relation to that of the strata (fig. 38); beyond this, that the dip of the strata being moderate, that of the cleavage is usually greater. In a country where the strata are much undulated, the cleavage may be and mostly is in parallel planes.

Fig. 38.—Parallel cleavage in contorted slates of North Devon.

Local Changes of Internal Structure.—We must defer to a later page the theoretical considerations which arise out of these facts,[1] and some other valuable data, collected by Mr. Sharpe, and later still by Mr. Sorby; but though a little out of place, we cannot forbear to add here a short notice of facts known in Switzerland, which distinctly prove one of the effects of heat upon common argillaceous shales, to be the alteration of their structure, so as to give a real vertical cleavage to a mass of horizontal laminæ of clay, as well as that induration which belongs to slate. The Lias shales of the Alps are so altered by proximity to the igneous rocks of that region, that in several places in and near the Valley of Chamouni they are commonly mistaken by modern tourists for genuine slates of the Primary system, and were always described as such by the older writers. This demonstrates that cleavages, and other peculiarities of structure, not produced in rocks by water, nor coeval with their deposition, have been occasioned subsequently, chiefly by the agency of pressure or molecular rearrangement.

Composition of Strata.

Chemical Deposits.—Under different circumstances water, at certain temperatures, and by the help of soluble acids or alkalies, dissolves various mineral substances. When, by evaporation, loss of heat, or a change in the composition of the liquid, these substances are no longer capable of remaining in solution in it, they separate in a more or less crystallised form, and the deposit which they occasion is termed a precipitate. By such processes lime, magnesia, and other earths and metallic oxides are first dissolved in water, and afterwards separated from it. In this way calcareous marls and irregular accumulations of limestone, in lakes and in the course

[1] These remarks on cleavage are based on observations by Prof. Phillips, and were mostly published in Encyclo. Metrop., 1833; Guide to Geology, 1834–6–51; Treatise on Geology, 1853; Brit. Assoc. Report, 1843.

of certain streams and at the mouths of some rivers, are thrown down. In ancient times also, the most abundant chemical deposit from water was limestone.

The chemical stratified deposits are principally limestones, or composed of carbonates of lime and magnesia, or are salt rocks with beds of chloride of sodium. This is not the place to discuss points of theory, and we shall therefore speculate no further at present on the origin of these deposits than to say, that the quantity of lime now held in solution in sea-water is subject to daily diminution through the agency of life, and experiences daily renewal by the inflow of streams from the land. The innumerable tribes of corals, mollusca, and other invertebrata, obtain the carbonate and phosphate of lime necessary for their skeletons, &c., from the salts of lime in the sea, and these salts are supplied by streams from the land, which have derived lime from the old rocks. The calcareous rocks are found to be almost wholly composed of shells, corals, crustacea, &c., and thus we perceive as a very general fact, that it is less by direct chemical reactions than by vital energy and the decay of organised fabrics, that thick calcareous masses of every geological age have been formed and are still forming in the sea.

Mechanical Deposits.—The mechanical agency of water is manifest in removing materials from one place and depositing them in another. Thus pebbles and sand and clay are transported by the tides and by rivers, and accumulated in low situations in regular layers, miniature representations of those thicker strata of the same ingredients which compose the crust of the earth. And as at the present day some materials are transported farther by water than others, and consequently more rounded by attrition, so the materials of the strata are likewise more or less worn and rounded, in proportion to the distance they have travelled and the friction they have suffered.

In many situations chemical and mechanical products are thrown down successively by the same waters, just as in the older strata limestones and sandstones occur alternately. We see, therefore, that the ancient deposits from water, which form layers several miles thick around a great part of the globe, are not essentially different, except in degree, from the lesser deposits now formed beneath the sea, and by streams from the land.

The mechanical deposits or strata composed of earthy materials, are distinguished by the coarseness, or fineness, or nature of their ingredients. The following scale will convey some notion of the gradations of size in the ingredients of mechanical deposits :—

Very fine particles, generally containing 20 to 30 per cent. of alumina...............	Clay, marl, shale, and slate.
Mixture of clay and sand........................	Sandy clay.
Sand with some clay.............................	Argillaceous sandstone.
Small fragments of hard siliceous minerals.	Sand, sandstone.
Sandstone including pebbles....................	Millstone grit.
Large pebbles united by sandstone or clay...	Conglomerate or puddingstone.
Pebbles disunited................................	Gravel.
Angular stony fragments reunited	Breccia.

Ingredients of Mechanical Strata.—Considered with reference to the *nature* of the ingredients which compose them, mechanical strata form another scale.

Thus gneiss, one of the oldest of these strata changed by metamorphism, is a compound of the same ingredients as granite—quartz, felspar, and mica; but these minerals, instead of being amalgamated (so to speak) together by crystallisation, are accumulated in successive laminæ more or less regular, and more or less soldered together. Some varieties of gneiss, therefore, differ from micaceous sandstone less than is commonly imagined, and often other varieties occur which have so slight a lamination and so much of crystallisation as to justly bear the name of granitic gneiss.

Sandstone sometimes contains rolled and broken pieces of crystallised felspar, such as that which occurs in the granite of Cumbria and Scotland. There is, therefore, every reason to conclude that coarse sandstones, like the Millstone Grit, have been derived from the waste of ancient tracts of granite and metamorphosed rocks. Nearly all sandstones contain a small amount of felspar.

Sandstones sometimes extend over vast districts, and are characterised by some remarkable mineral ingredient; as, for instance, the Green-sand of England, France, and Switzerland, which is distinguished by the presence of a peculiar green mineral, termed Glauconite or silicate of iron.

Conglomerates, on the other hand, are generally constituted of fragments from the neighbouring mountains or coast. Thus the red sandstone of the Vosges mountains contains quartz pebbles derived from the slate rocks of the vicinity; the Old Red conglomerate of England varies in composition according to its locality; that of Herefordshire contains much quartz.

Whole Series of Strata.—The whole series of stratified rocks, then, consist of alternate deposits of limestone, sandstone, and clay, with a few layers of coal, rock-salt, flint, iron ore, &c. The modes of alternation are different in different parts of the series and in different situations. Thus the Siberian limestones are sometimes enclosed between beds of slate, the Carboniferous Limestone alternates with sandstone and shale, the Lias limestone lies in marly clays and shales, the Coralline Oolite alternates with calcareous sandstone. Generally, the different strata are distinguishable by their mineralogical characters, but not always. When the circumstances of the deposit were nearly similar, as in the accumulation of the Carboniferous Limestone and some of the oolites, the strata are remarkably alike; and often particular beds of one rock are scarcely to be distinguished from beds of another rock. The Old Red Sandstone and the New Red Sandstone formations are physically very much alike; it would be difficult by mere mineralogical methods to discriminate the great clay deposits which separate the oolitic limestones, and many sandstones of very different epochs are almost undistinguishable from each other. Hence we may infer that nearly the whole series of strata is the result of many repetitions of similar

mechanical and chemical agencies operating in waters under similar conditions.

Alternation of Beds.—When sets of strata are in contact—as, for instance, limestone lying upon sandstone—it often happens that while the limestone above and the sandstone below are unmixed with other matter, there is a middle set of beds composed of alternate layers of the sandstone and limestone. Thus, let *a* be the Coralline Oolite of England, and *b* calcareous sandstone beneath; the middle beds a' a'' b' b'' are alternately oolite and sandstone.

Exchange or alternation of Beds.

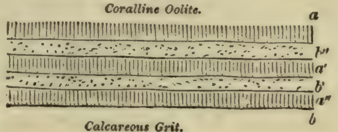


Fig. 39.

In such a case, therefore, the two strata are said to *exchange beds*, or to be subject to *alternation* at their junction, and the phenomenon seems to have been occasioned by temporary cessations of the deposit of sandstone allowing the limestone which would normally have been only a cement to the sand to accumulate and form a limestone deposit.

Gradation of Beds.—In other instances, the two strata pass into one another by imperceptible gradation; as for instance, the Oxford Clay of the Yorkshire coast graduates into the Calcareous Grit above so completely, that the bluish colour of the crumbling shale below is shaded off without any hard line into the yellow solid beds of grit above. See fig. 40.

Gradation of Strata.

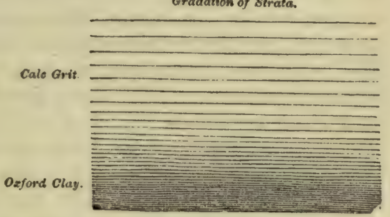


Fig. 40.

In either case it seems quite evident that no considerable break or interval of time happened between the different contiguous deposits; one bed was no sooner formed than another was laid down and deposited upon it. By careful study of these phenomena it appears that, bed by bed, and rock after rock, the whole series of strata, even to miles in thickness, were successively and almost unremittingly accumulated, and buried and covered up the shells and other organic beings which were then living in the water, or on the shore, or drifted into it from the land. The strata are, therefore, the best witnesses of the lapse of time, and of the changing conditions of land and water during their deposition.

Proportions of Chemical, Organic, and Mechanical Deposits.—Assuming limestones to be of chemical or vital origin, and sandstones, clays, &c., to be mechanical deposits, and putting for the present out of consideration the detached organic remains which abound, especially in calcareous strata, we shall be able by comparison of the thickness of the several rocks to present a tolerably accurate notion of the relative proportions of chemical, organic, and mechanical deposits.

If we take our examples of these strata from Great Britain, it may, perhaps, be found a sufficient approximation to the ratio now sought, to say the mechanical are to the chemical deposits from water :—

In Palæozoic or Primary strata, . . .	20 to 1
In Mesozoic or Secondary strata, . . .	4 to 1
In Cainozoic or Tertiary strata, . . .	10 to 1

In these comparisons regard is had to the different proportions which prevail in different districts. They would be very different estimates for the Tertiary series in the Isle of Wight, and that of the London basin; and for the oolites near Bath, and those near Whitby.

From this comparison it would appear that the ratio of chemico-vital to mechanical strata is greatest amongst the Secondary deposits, and least amongst those of the Primary periods—a circumstance on which depend principally the well-marked general characters of the Secondary series of rocks. It should, besides, be observed, that calcareous matter very finely divided exists in nearly all the sandstones and shales of that series, and sometimes so abundantly as to change, locally, Lias shale into argillaceous limestone, and Calcareous Grit into arenaceous limestone, or coarse oolite. In Secondary strata, the great and prominent masses of limestone almost invariably attract the attention and direct the classification, and thus it happens that while numerous layers of clay and sand pass nearly unobserved, or are merely noticed as *interpolated beds*, almost every calcareous bed has its characteristic local name. The almost universal diffusion of calcareous matter through the mechanical strata of this large group, combined with the great regularity and persistence of the limestones, generally suggests theoretical notions as to the cause. The observer soon learns to consider the operations by which sandstones and some clays were rapidly accumulated with intermitting action, like the periodical floods of a river, or some less regular inundations or depressions; while the production of limestone is regarded as the result of one continuous and almost uninterrupted series of chemical and organic changes. This opinion, strengthened by the gradations between calcareous and sandy or argillaceous laminæ, and by frequent alternation amongst even their thinnest portions, derives plausible arguments from the distribution of organic remains through the several strata. In some cases they teach us plainly that sandstones, even of great thickness, were the products of temporary and often of very local floods, which swept down from the land the remains of animals and plants then in existence, or result from currents of water due to tidal action or coast interference; but, tried by the same tests, the calcareous rocks appear to have been of slower and more equable production, in clearer, and more tranquil, and often deeper waters. This is in harmony with the present system of natural operations. The pebble beaches of our actual shores and the gravel and sand-banks of our shallow seas may be compared with the

often thin and irregular sandstones and conglomerates of earlier ages; the finer clays which fill the broader and deeper hollows of our seas, because such fine sediments are held long in suspension by water, are quite similar in position to the older argillaceous deposits; and our modern coral reefs and the shell beds which accompany them, produced in clear pelagic waters, unmixed with sediments from the land, are in many respects exactly the representations of the old limestones of Wenlock, Bakewell, Calne, and Orford.

CHAPTER VII.

THE PHYSICAL AND MINERAL HISTORY OF STRATIFIED ROCKS.

ALTHOUGH the greater changes which have taken place in the history of the earth are only to be discovered by following the several beds of rock through the country, and observing their relations to each other, and alterations in mineral character and in fossils, yet much may be learned concerning the conditions under which each deposit was accumulated, and sometimes even the direction and district from which the deposited material was derived, by minute and even microscopic examination of the particles of which a stratum is built up. This kind of research has been rendered possible by the labours of Dr. Sorby [1] and Mr. John Arthur Phillips,[2] and it is on the basis of their researches that we give an indication of the ways in which sands, clays, and limestones may be made to yield evidence of their history and origin.

Sand.

By sand we understand the materials constituting the fine-grained silicious rocks called sandstones. This sand has in every case been derived from the destruction of igneous or metamorphic rocks, and in some cases of chert or flints. The quartz from granite consists of separate grains which often have an irregular and complex form, but the quartz from felsite is much more truly crystalline, and the planes of the crystals are frequently perfect though the angles are more rounded than in the quartz from granite. Sometimes the grains are corroded as though partly dissolved by the action of the alkalies liberated when the associated felspar was decomposed. The quartz derived from gneiss and mica-schist, especially when those rocks have a thin foliation, is remarkable for being flattened in the plane of foliation, and consists of numerous small crystals dovetailed together, so that when broken up it gives rise to a fine-grained sand, or a sand containing grains which show a compound structure; and if the parent rock contained mica, thin plates of mica are found between the parallel grains of quartz. When the grains are observed under the microscope they often show fluid cavities, frequently with bubbles. This character is conclusive

[1] H. C. Sorby, Address Quart. Jour. Geol. Soc., vol. xxxvi.
[2] J. A. Phillips, Quart. Jour. Geol. Soc., vol. xxxvii. p. 6.

evidence that the quartz was derived from a rock which solidified from a heated condition under great pressure. The fluid cavities are most numerous in the Cornish granites, and there they often contain cubic crystals of alkaline chlorides. The schists of Scotland contain but few fluid cavities, and crystals have never been observed in the cavities of these rocks, or in any Scotch granite. There is a further difference between the Scotch and Cornish granites in the fact, that the former generally contain in the grains of quartz fine hair-like crystals of the mineral rutile, while in the latter the grains abound in small prisms of tourmaline. The quartz crystals of some volcanic rocks, like the rhyolites, sometimes contain six-sided or imperfectly rhombic enclosures of coloured glass with accompanying bubbles. The presence of volcanic glass would always indicate denudation of a volcanic rock. The grains of sand are rarely obtained direct from the rock which yields them without experiencing a large amount of wear. This attrition is due to transport of the material by rivers, and grinding by the waves on the sea-shore. Some ancient sand-beds are made up of grains which are unworn and practically new, while the grains on many a modern sea beach are of vast antiquity, and have formed part of several geological formations, in each of which they have been worn. When we examine some of the modern sands in process of formation, the amount of wear is found to be unexpectedly small; thus the sand of the river-terraces at Dunkeld is almost entirely angular, and presents the features characteristic of sand derived from schists. The sands of the Arabian, Egyptian, and great African deserts, on the other hand, are exceptionally worn, every grain presenting the characters of a miniature pebble, a feature which results from the agency of wind in triturating the grains against each other. The sand which occurs in the decomposed granite of Cornwall is separated from the rock by artificial washing in the china clay works of that district, and the characters of the grains have been observed in the St. Austell river, which has a fall of from 150 to 470 feet to the sea. Here the grains are seen to consist of a mixture of quartz, felspar, and a little mica. They vary in size from over $\frac{1}{20}$th inch to a fine sand of less than $\frac{1}{100}$th inch.

The fragments of quartz and tourmaline are sharp and unrounded, but the edges of the mica and felspar are distinctly rounded. The felspar grains always have an external coating of clay due to decomposition. As the sand becomes finer the grains become less worn, and the proportion of mica is larger than in the coarse sand, and there is less felspar. Attempts have been made by Professor Daubrée to estimate the distance that a grain must travel to show a definite amount of wear, and he concludes that before a grain of quartz $\frac{1}{50}$th inch in diameter can assume the appearance of a miniature pebble it must undergo the same amount of abrasion as would result from travelling three thousand miles along a shore. Grains, however, from being corroded in the manner already indicated, sometimes become modified in outline without much wear, and occasionally they are singularly fractured; but frequently grains which were rounded by attrition have

quartz deposited upon them from water infiltrating through the rock so as to present the aspect of perfect crystals absolutely free from wear. This deposited quartz appears to be almost always derived from the decomposition of associated felspar in the sand, though in the Vosges district M. Daubrée finds reason for attributing it to the local action of heated water; but since the china clay always develops from its free silica sharp crystals which sometimes reach a length of three inches, we have in this action a sufficient explanation for the crystalline condition observed in so many British sandstones. By placing a number of grains of sand from a given deposit under the microscope, and counting the proportion of worn to unworn grains, Dr. Sorby has shown that the sand in several formations is derived from different sources. He observes that the sand from the Boulder Clay at Scarborough is fresh and angular, showing few or no rounded grains, and that the modern beach at Scarborough, which is largely derived from the Boulder Clay, has the grains scarcely more worn. In the Thanet Sands

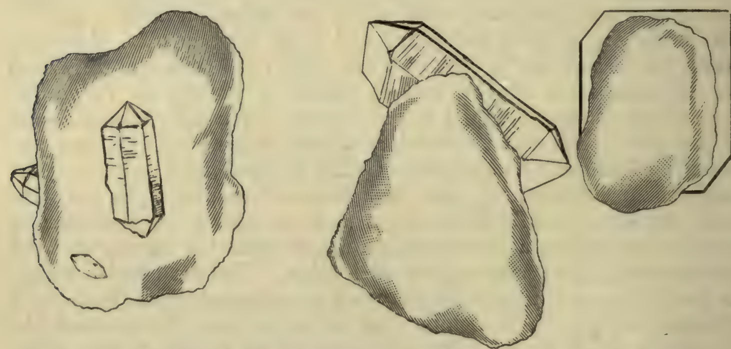


Fig. 41.—Grains of sand magnified, with quartz crystals upon and around the grains. After J. A. Phillips and Sorby.

at Crossness, and in the Hastings Sands at Hastings, one-half of the grains are worn. In the Upper Greensand the amount of wear increases as we pass from Dartmoor to the east, one-tenth of the grains being worn at Haldon Hill, one-fifth in the Isle of Wight, one-third in Sussex, and one-half in Kent, indicating that as the deposit recedes from the region from which it was derived the amount of wear increases. Mr. J. A. Phillips, F.R.S., has examined the chief British sandstones, and it may be useful here to give a brief summary of his conclusions with regard to some of the more important.

The Barmouth grits in the Lower Cambrian series of North Wales, between Barmouth and Harlech, often enclose angular fragments of quartz fully a quarter of an inch in diameter. The deposit is an aggregation of quartz and felspar united by a silicious cement tinged greyish green with a mineral which is probably chlorite. The quartz contains a few fluid cavities with moving bubbles. The felspar is of two kinds, orthoclase and probably oligoclase. Some of the quartz contains

crystals of rutile, and the cement contains calcite, magnatite, iron pyrites, and a few imperfect garnets. Near Harlech, the sands are finer and purpler, but only differ in the cement containing crystals of epidote. When analysed, silica forms 80 per cent. of this rock. The well-known sandstone of the Stiper stones west of the Longmynd, near Shrewsbury, has grains with an average diameter of one-fiftieth of an inch; some, rounded almost like pebbles, are converted into perfect crystals by a deposit of transparent quartz upon the sand nucleus, and the grains are generally so closely cemented by crystalline silica as to form a quartzite. The few grains which contain fluid cavities usually have the cavities full. Felspar is not abundant.

The grey grit of Aberystwith consists of nearly equal proportions of quartz grains and felspathic grains cemented by silica. Some of the grains are the $\frac{1}{35}$th of an inch in diameter, generally rounded, though a few are sharp; the quartz contains very minute fluid cavities which are generally full, though some enclose moving bubbles, and some crystals contain needles of tourmaline. The felspar is partly triclinic, and fragments of a volcanic rock like basalt occur; in the silicious cement are small flakes of mica and a few crystals of iron pyrites. This rock has been derived in part from the disintegration of quartz felsite.

The May-Hill sandstone is chiefly composed of angular grains $\frac{1}{200}$th of an inch in diameter, united by a turbid silicious cement; there are a few larger grains, these like the smaller ones contain hair-like crystals of rutile, but fluid cavities with bubbles are rare. In the Lickey Hills, in Worcestershire, the rocks of this age have the grains greatly rounded, the diameter of $\frac{1}{50}$th of an inch; fluid cavities with bubbles are numerous in some of the grains, absent in others; rutile and tourmaline both occur in the quartz in minute crystals.

The Denbigh grit consists chiefly of a fine-grained cement containing both minute and larger fragments of quartz with felspar and brown mica; and the quartz sometimes encloses needles of tourmaline, sometimes crystals of rutile. There are few cavities with bubbles.

In the Devonian rocks the grits near St. Austell are a mixture of angular pieces of quartz and felspar; the quartz includes crystals of tourmaline and few fluid cavities. The felspar is partly orthoclase, partly triclinic, and the rock contains a little silvery mica and a few crystals of pyrites. Specimens from Ladock enclose many angular fragments of a greenish slate; these are included among small rounded grains of quartz, felspar, and other substances, among which are pieces of volcanic rocks closely resembling the Cornish greenstones and dunstones; but a second specimen from the same locality is chiefly made of angular fragments with more abundant fluid cavities in the quartz, some grains of which contain epidote and flakes of white mica. The felspar is chiefly triclinic, and there are a few minute garnets and some fragments of organic rocks. These data sufficiently indicate the varied nature of the materials from which the Devonian grits of Cornwall were derived.

In the Carboniferous system, Mr. Phillips has examined a fine-grained sandstone in Cumberland belonging to the Yoredale series. The quartz is angular and generally free from fluid cavities. When cavities do occur they are full; the rock also contains a little felspar and kaolin, and some white mica. The Millstone Grit in Cumberland consists almost entirely of grains of quartz $\frac{1}{125}$th of an inch in diameter, bound together with a silicious cement, and containing a little felspar. The quartz includes occasional fluid cavities and a few needles of tourmaline. The sandstones of the Lower Coal Measures near Bradford consist in the main of fragments of quartz and felspar; the quartz sometimes encloses tourmaline, but contains few fluid cavities; the felspar is chiefly triclinic, and is associated with some kaolin, a few garnets, and flakes of dark and colourless mica. The fragments in this rock are $\frac{1}{250}$th of an inch in diameter; but many of the Carboniferous sandstones are chiefly formed of quartz grains which have crystallised in the positions in which they now occur, for they show no sign of abrasion, not having lost a point or an angle.

The Permian sandstone of Cumberland, which has a reddish tinge owing to the opaque ferric hydrate in the cement, is a mixture of angular fragments and minute crystals of quartz and a little felspar; the quartz grains contain few fluid cavities, and have a diameter of $\frac{1}{200}$th of an inch. The flakes of colourless mica are water-worn.

The Triassic sands vary considerably. Some of the Bunter sandstones of Lancashire and Cheshire, known as "Millet-seed Beds," flow between the fingers like shot; these have most of the grains rounded like miniature pebbles; their diameter is from $\frac{1}{50}$th to $\frac{1}{200}$th of an inch; they are partly quartz, partly felspar. The quartz grains are frequently covered with transparent crystalline silica. Such beds may well be blown sands, like those of existing deserts, united by a ferruginous cement which has invested the grains. In many of the beds the quartz is almost entirely in the form of minute crystals; such a rock is well seen near Ormskirk. The Upper Trias or Keuper generally consists of well-rounded silicious grains. At Dymoke, in Worcestershire, the quartz sometimes encloses crystals of rutile and fluid cavities with bubbles; part of the felspar in this rock is triclinic, and there are a few flakes of white mica. In the cement are minute garnets and a little kaolin. The beds called water-stones include angular fragments of dark-coloured slate sometimes half an inch in diameter; the quartz grains are often $\frac{1}{15}$th of an inch in diameter, much rounded, and contain fluid cavities; there is some felspar. Mr. Phillips believes that the grains in Triassic sandstones which contain fluid cavities and crystals of tourmaline are from a different parent rock to those grains from which the cavities are absent.

The Upper Lias sand in Gloucestershire has a calcareous cement, the quartz grains in which are generally angular, though some of the angles are a little rounded; they are $\frac{1}{200}$th of an inch in diameter, sometimes enclose fluid cavities without bubbles, and are associated with numerous fragments of tourmaline and garnet, and probably a

little felspar. This rock near Whitby also contains a few small garnets, but the quartz has no fluid cavities; the grains are $\frac{1}{75}$th of an inch in diameter, and have their angles removed, but are surrounded with crystalline quartz which forms the cement. The quartz in this rock is such as might be obtained from the decomposition of clay slates. Sand from the Portland Stone in Wiltshire is rounded, quartzose, and contains few fluid cavities, generally without bubbles; the grains vary from $\frac{1}{70}$th to $\frac{1}{250}$th of an inch. They are associated with but not enclosed by ovoid grains of carbonate of lime.

In the **Wealden Sands** the quartz consists of slightly rounded colourless grains almost free from fluid cavities, but enclosing some hair-like crystals of rutile. The cement is partly carbonate of lime, partly flint.

The **Neocomian Sand** called Carstone at Hunstanton is mainly composed of rounded grains of quartz containing tourmaline and rutile, with a few fluid cavities generally free from bubbles. This quartz is mixed with small granules of dark-brown pisolite, and contains a few scales of mica and a little felspar. The rock contains less than 50 per cent. of silica and 30 per cent. of oxide of iron, though sometimes the amount of iron is more, and the silica somewhat less. The Sevenoaks stone of the Lower Greensand consists of chert, in which there are only occasional grains of quartz, some of which are rounded, while others are angular.

In the **Hertfordshire Puddingstone**, which occurs below the London clay, the flint pebbles are united by a concrete, partly formed of flint and partly of fragments of quartz. The quartz is all angular, greatly in excess of the flint, and sometimes contains fluid cavities.

The brilliantly coloured sands of Alum Bay, of **Lower Bagshot** age, like the Triassic and Permian sands, lose their colour when boiled in hydrochloric acid. The quartz grains are all worn, though not completely rounded; occasionally they contain crystals of tourmaline, and sometimes fluid cavities, but rarely enclose bubbles.

In the **Headon sands** of Hordwell Cliff, all the quartz is completely rounded, and fluid cavities with bubbles are abundant. The rock contains no fragments of felspar.

The marine beds at the top of the Hempstead series in the Isle of Wight include sand composed of quartz grains which are well rounded.

The **Boulder Clay** at Holywell in Flintshire yields sand of a varied character, some grains being small quartz pebbles, others rounded particles of felspathic and other rocks. Some unworn quartz grains derived from crystalline sandstones are observed, associated with rounded grains derived from the millet-seed sandstone.

This detailed analysis of some of the important beds of sand which occur in the British strata may serve to point out not only the great field which is open to further investigation by examination of the conditions under which the beds were accumulated, but is also

indispensable to a right understanding of the minerals, which may be produced when such sandstones are metamorphosed by the action of heat and pressure, so as to become reconverted into crystalline rocks, such as schists; for the presence of felspar, iron, and many other minerals, renders the composition and variety of such schists readily intelligible.

Glauconite.

This is one of the most characteristic minerals found in sand. The grains are usually dark green, amorphous, and on being powdered yield a bright-green colour; frequently they invest the cells of foraminifera.

Glauconite is a double silicate of iron and alumina, with a certain amount of the alumina replaced by magnesia, soda, and potash. Its composition is nearly identical with seladonite, the green earth found in the vesicular cavities of certain basaltic rocks. It is known to be produced by the alteration of augite and hornblende, but in some of the rocks it appears to have formed by replacing particles of yellow ferruginous mud. Its origin is concretionary, and it is probably formed at the time of deposition. At the present day considerable deposits of glauconite are found off the coast of North America, so that their existence was attributed by Professor Rogers to the influence of an ancient Gulf Stream. Similar deposits have been met with during the "Challenger" exploration off Portugal, off the east coast of Australia, and off the Crozet Islands, at depths of 400 to 600 fathoms; and it may certainly be inferred that a stream flowing in the ocean from a warmer to a colder region would inevitably have a tendency to precipitate certain of the mineral substances which the water originally held in suspension when its temperature was higher. Glauconite occurs in the green slates of the English Lake district, where it fills the cells in fragments of pumice; a similar material is found in the slate of Penrhyn. But glauconite is most characteristic in the various Secondary and Tertiary sands. In the Lias, sandy beds of the Forest Marble, Calcareous Grit, Portland Rock, Neocomian Sand, and Upper Greensand, it often gives a colour to the deposit. It is found at the base of the Thanet Sands, and throughout those beds, and in the Bracklesham Beds, and Barton Clay. It sometimes mineralises fossils. Its abundance and constant repetition in the rocks of the South of England strongly suggest that its existence is due to the same physical causes, such as the denudation of like plutonic rocks. Nevertheless, in chemical composition it is curiously similar to the residue of chalk which would be left after the carbonate of lime has been removed; and since there is abundant evidence that the carbonate of lime of the Chalk has been removed subsequent to the deposition of the Tertiary beds so as to interpose a stratum of unworn flints on top of the Chalk, Professor M'Kenny Hughes has argued that the glauconite in which those flints are embedded has been formed *in situ* out of the residue of the Chalk, and may be now forming.

Sandstones sometimes contain a large amount of brown oxide of iron. This is due to infiltration. Occasionally sandstones contain beds of chert, as in the Upper Greensand of Devonshire, Dorsetshire, and the Isle of Wight, and in the Lower Greensand of Sevenoaks; but since chert is only developed where the sandstone is calcareous, and is nothing but flint more or less porous, which contains some calcareous matter, its origin will be better considered in discussing the flints which are found in limestones. Small masses of phosphate of lime sometimes abound in sands, especially the Upper Greensand of the Isle of Wight and the Neocomian Sands of Bedfordshire and Cambridgeshire, but since they are more characteristic of deposits which have a floor of clay, they will be treated of after discussing the history of clays.

Clay.

No such careful and detailed examination has been made of existing mud and clay as of sand or limestone. The subject is much more difficult, and as a rule, nothing can be distinguished by the microscope but more or less irregular granules, minute flakes of mica, and sometimes needle-like prisms, with variable amounts of calcareous granules and sand. There is necessarily every gradation between sands and clays on the one hand, and limestones and clays on the other; and the observations on the deposits now forming are too few to completely demonstrate the conditions under which many of the newer clay beds were formed. It may, however, be regarded as certain, that when the quartz grains in clays are coarse the clays are derived from granite, while when fine they are due to the destruction of schists. The newer clays, as a rule, give no indications of pumice or volcanic dust, but many of the older muds now changed into slate rocks appear to be entirely of volcanic origin. Mr. Sorby has noticed that fine-grained mud obtained in the South Pacific from a depth of 2600 fathoms, possesses the following remarkable property :—The grains of sand do not separate from the finer mud and subside, but gather the finer particles about them into a compound granule, and this process rapidly clears the water. But it has been determined experimentally, that the solid matter in such muds only amounts to 11 per cent., while in shales the solid matter is at least 75 per cent., so that when pressure squeezes the water out of these clays they may be reduced to one-sixth of their original thickness, and this change would tend to develop in the planes of bedding exactly such a fissile structure as is commonly met with. Clay may originate in many ways; the red earth found in caves, and washed in by the streams flowing through them, is obtained from the destruction of the neighbouring limestone rocks, for after the carbonic acid gas dissolved in water has carried away the whole of the carbonate of lime, there remains an insoluble residue of silicate of alumina and oxide of iron, which, although forming but a small percentage of the limestone, yet has often contributed to the accumulation of small deposits, such as those in caves. In the exploration of the Atlantic by the "Challenger," it was observed that there is much

volcanic matter upon the sea-bed near to volcanic centres. Two such masses occur in the middle part of the Atlantic, one obviously derived from the volcanic islands to the west of Northern Africa, and the other derived from the volcanoes of the West Indies and Central America. These are areas occupied by red clay which Mr. Murray attributes to the decomposition of pumice and other volcanic materials, finding among the clay many fragmentary crystals of felspar, augite, and other of the minerals which occur in volcanic rocks. This material has been transported by the winds, and decomposed on the sea-bed often at a depth of between two and three thousand fathoms. These regions of the ocean abound in concentric nodules of black oxide of manganese.[1]

Kaolin, or china clay, is actually manufactured from the granite at St. Austell in Cornwall, and near Plympton in Devonshire, by breaking up the decomposed rock, and washing it on an inclined plane, with pits arranged to catch the quartz, tourmaline, mica, and other minerals, until the purified clay obtained from the felspar is deposited in tanks and dried for export. Geological deposits almost identical in character occur in the Bagshot Sands, especially at Poole and Wareham. It may be interesting to remark that the tesselated pavements in general use are produced by compressing dry clay till it becomes solid, though as a rule heat is subsequently applied to increase the hardness.

Clays when sandy are termed loam ; and when calcareous are marls. Occasionally, as in the Kimmeridge Clay, bituminous beds of considerable extent occur, and impart to the clay a combustible quality, enabling it to be burned as fuel, a totally different property from the spontaneous combustion sometimes set up in clay cliffs by decomposition of the iron pyrites.

Slate.—Many of the so-called clay slates differ from modern deposits of clay in containing a very small amount of kaolin material and an immense amount of mica, in flakes too small to be visible to the naked eye, but which give a sort of silky lustre to the rock when they lie in the plane of fracture, as in some of the black slates near Llanberis.[2] With the mica are numerous needles or small black crystals like hairs, probably of hornblende and magnatite.

The **Devonian Slates** are of similar character. When the crystals of mica have formed *in situ*, they often abound about special centres, but, as a rule, the mica is evenly distributed, and appears to have been derived from the disintegration of an older rock, such as the micaceous

[1] Volcanic ashes and lapilli occur in great abundance in the red clay of the Pacific, which has its centre about the Low Archipelago, and extends towards the Sandwich Islands. The lapilli are all of the basaltic type, but often become glassy. Many of the palagonites are identical in character with those of Sicily, Iceland, and the Galapagos Islands. The most abundant minerals are plagioclase, augite, magnetite, a little sanadine, and hornblende. Quartz is absent. Many of the lapilli are found to be cemented together with zeolites like christianite. Minute crystals forming radiating masses of the same zeolite occur in prodigious quantities in the red clay so as to form, according to the estimate of the Abbé Rénard, about a third of its bulk. These zeolites are evidently formed *in situ*. Dr. Sorby has detected similar specimens in the Gault.

[2] H. G. Sorby, Quart. Jour. Geol. Soc., vol. xxxvi.

felsites, which would have yielded materials exactly similar to the micaceous clay slates, for when the particles of mica are so exceedingly fine, they are not separated from the kaolin.

Cambrian Slates.—Associated with the slates of Bethesda, near Bangor, is a bed of felsitic ash. Some of the fragments are an imperfect pumice. There are quartz grains, which appear to have been derived from a quartz felsite, for they occasionally enclose felsitic material similar to the felsites of the neighbourhood. There are frequently grains and needles of magnatite, and sometimes black grains of basalt. Fragments of augite appear to have been altered into chlorite. If, observes Dr. Sorby, the micaceous base of this ash were worn down into dust in a volcanic crater, or more completely decomposed by weathering, and the material afterwards sorted by gentle currents, it would yield a deposit corresponding in all essential particulars with the fine-grained slates of Penrhyn and Llanberis. Other beds in the same group of rocks contain little mica and much kaolin, and were evidently derived from an igneous rock which contained relatively more felspar than that which yielded the Llanberis slates.

When examined under the microscope, it is amazing to see how frequently some beds, like the pencil slate of Shap, consist almost entirely of mica. These Shap slates show the particles disturbed by pressure, and in process of being arranged into the parallel films which constitute cleavage.

The **Green Slates** of Cumberland and Westmoreland are well known to be almost entirely derived from volcanic ashes. Specimens from Rydal and Langdale show the original material very little altered. Sometimes the fragments are $\frac{1}{10}$th of an inch in diameter, and are derived from very vesicular lavas or rocks passing from the condition of pumice through perfect glass to a devitrified felsite, owing to the development in it of minute crystals. Quartz is frequently absent, just as in the South Pacific red clay; and when occasional grains of quartz are found, the cavities in them are free from fluid. At Ambleside large fragments of pumice occur with their cavities infiltrated with calcite exactly as is the case at the present day in the fine-grained mud of the ocean. Frequently, however, the rock is more changed, so that it would be impossible to tell whether the ash was erupted and changed in the water, or whether heat took any part in the process. Much of the felspar, augite, and garnets may have originally belonged to the ash, but other minerals may have been formed where they are now met with. The Green Slates of the Lake district are formed of fragments, so compressed in the plane of cleavage that it is impossible to tell whether they were derived from felsite or reconstructed out of an older slate.

The slates of Loch Awe, although presenting an ordinary appearance to the eye, show under the microscope all the characters of a very fine-grained schist. The slates of Moffat are of the usual granular type, mixed with others which are highly micaceous, in which are 3 or 4 per cent. of glassy fibres like the Pélé's hair of the Sandwich Islands.

The **Chiastolite Slate,** on the flanks of Skiddaw, abounds in crystals of chiastolite and hornblende, which have been developed *in situ*, and the development of these and other minerals must always be considered to depend chiefly upon the original composition of the clay; for even the augite, in the consolidated peperino from Vesuvius, has become changed into a zeolitic substance, which has thoroughly hardened the whole deposit.

The chiastolite in some of the black slate of Ivy Bridge in Devonshire may be seen in process of being changed into mica, and masses of mica are otherwise developed about special centres. The slate of Liskeard contains scattered concretions, composed of crystals of mica and quartz, which have been formed *in situ*. These little masses, only $\frac{1}{500}$th of an inch in diameter, have been termed the very germs of mica schist, and the rock appears to present a first stage of the development of that material. In other slates the concretions of quartz and mica have become so abundant as to have coalesced and thrown the residue of the rock into patches, which may possibly be incipient garnets. This slate is seen near to granite near Wicca Pool. From such a rock the transition is easy into mica schist, where the crystals all lie in definite directions, which may be parallel to the plane of stratification, parallel to the plane of cleavage, or parallel to joints; but even when the structure is perfectly developed, original grains of sand, milk-white, water-worn, and angular, often occur, associated with felspar a good deal decomposed, and felspathic grains, which appear to have been derived from a felsite. It has been estimated that these grains of sand occur in about one-fifth of the slates and one-fifth of the schists. The grains of quartz often contain crystals of rutile and minute granules and fluid cavities, in which sometimes crystals of alkaline chlorides are found. No granite or felsite is known in which the quartz grains show all the characters exhibited by the schists of the central Highlands of Scotland, and hence the parent rock for those ancient muds is supposed to have been either a quartz felsite, or a granite and a felsite denuded together. The proof that the crystals of schists were not deposited where they occur is furnished by the fact that they are fitted and dovetailed together in a complicated and accurate manner, such as always occurs when crystallisation takes place *in situ*.

Septaria.

Septaria occur in flattened ovoid masses in nearly all clays. They usually contain 65 per cent. of carbonate of lime, 18 per cent. of silica, and the remainder is about equal proportions of alumina and protoxide of iron, though the amounts of these ingredients vary. They are often called cement stones, because used for the manufacture of roman or hydraulic cement. The stone is not durable, though it is dense and hard. When these concretions are broken across, they are observed to show numerous cracks, which are widest in the middle of the concretion, and radiate in many directions from the centre towards the circumference. When these cracks are filled with crystalline deposits,

tabulæ or septa are produced, which give a name to the concretions as well as manifest their most striking character. The septa originate in nests of minute concretions. If a small concretion only an inch or two long is examined, the internal cracks are seen to be empty, and the external surface is visibly increasing in size. We then learn that, as new matter is aggregated to the outside, it is soft, and consists more of clay than of carbonate of lime. Afterwards the carbonate of lime becomes infiltrated into the outer clayey layer, and enters into crystalline combination, so as to expand the outer layer more than the internal part. This splits the concretion internally but not externally, and thus, as the whole mass enlarges, the system of internal cracks also becomes better developed, forming cavities in which water may accumulate, and deposit various crystalline substances on the margins of the fractures. As already observed, septaria are spread in horizontal layers, and formed out of calcareous material, which was originally spread continuously through the clay, but became aggregated about centres by the solvent action of waters slowly passing through the deposit.

Phosphatite.

Phosphate of lime, in the concretionary form known as phosphatite, is perhaps more typically associated with clays, though it sometimes occurs in both sands and limestones. In internal structure the masses are commonly amorphous, though in some rare cases they are septarian. In external appearance they differ with the several deposits. The oldest known bed is found at the top of the **Bala limestone**, immediately under the shale that covers that rock, and is chiefly seen near the town of Llanfyllin and in the Berwyn mountains to the north of Dinas Mowddwy.[1] The bed varies in thickness from ten to fifteen inches, and consists of concretions which vary in size from that of an egg to a cocoa-nut. They are coated with graphite, more or less polished and cemented in a black matrix. They contain from 40 to 60 per cent. of phosphate of lime. The underlying bed of limestone sometimes contains from 15 to 20 per cent. of phosphate of lime, and when the bed of concretions becomes separated into two or three layers it is parted by thin phosphatic limestone. There appear to be few traces of organisms in the concretions. Perhaps the most extraordinary thing in connection with this deposit is the circumstance that in its western outcrop in the flanks of Aran Mowddwy, sulphur has almost replaced the phosphate of lime.

Phosphoric acid is found in small quantities in some of the oolitic limestones; and the Cornbrash, so named from breaking up into a soil which yields abundant crops of corn, contains a very appreciable percentage of phosphate of lime. In the Speeton Cliffs, a phosphatic band occurs on the horizon of the Portland beds. Another important deposit is found in the **Neocomian rocks** of Bedfordshire and Cambridgeshire. Here the deposit is concretionary, largely mixed with fragments of highly altered metamorphic rocks and fragmentary

[1] D. C. Davies, Quart. Jour. Geol. Soc., vol. xxxi p. 357.

fossils, which indicate considerable denudation of the underlying Secondary strata and more ancient rocks. The concretions are yellowish brown, of the average size of a chestnut to an apple; the surface is sometimes smooth and sometimes irregular. The bones of extinct reptiles which occur in the deposit are always mineralised with phosphate of lime. The bed is rarely more than a foot or two in thickness.

In the **Gault** there are several beds which contain concretions of phosphate of lime; first at the base in the zone of *Ammonites interruptus;* secondly, a thin band an inch thick in the lowest zone of *Ammonites auritus;* thirdly, in the zone of *Ammonites De-la Ruei.* A thicker bed, ten inches thick, occurs in the zone of *Ammonites mammilaris* at the junction of the Folkstone beds and Gault, and also at the junction of the Upper and Lower Gault, and other bands are found higher up. In some localities, as at Farnham in Surrey, and Puttenham in Buckingham, the bed of phosphatic nodules is sufficiently thick to be worked for the manufacture of super-phosphate of lime. On the opposite coast of France, at Wissant, the nodules of phosphate of lime in the Gault are particularly abundant.

The middle division of the Hunstanton limestone, in Norfolk, has a concretionary character, but the quantity of phosphate of lime is only about 10 per cent.

The **Upper Greensand** is particularly rich in concretions of phosphate of lime in Cambridgeshire, Bedfordshire, and adjacent districts. The nodules are a very dark brown, sometimes tinged green externally with glauconite, grains of which abound in the marl in which they are embedded. The nodules are extremely irregular in form and rarely more than three or four inches in diameter, though rolled masses are sometimes a foot long. Almost all the organisms are more or less mineralised with phosphate of lime. This deposit rests on the Gault.

Beds of phosphate of lime occur at or near the base of both the **Coralline** and **Red Crag** where those beds rest upon the London Clay. The bed is usually a foot or two in thickness; the nodules are usually more or less smooth and sometimes polished, of a reddish-brown colour. Among them occur many fossils derived from middle Tertiary beds and London Clay, with numerous contemporary remains of vertebrate animals. There has always been some difficulty in accounting for the existence of these deposits. It is well known that the island of Sombrero in the West Indies has the limestone rock so mineralised with phosphates as to be quarried and exported for the manufacture of artificial manure. Similar deposits occur at Curaçoa, but we have no evidence as to whether this condition is entirely due to infiltration from guano deposited on the rocks, or to the former growth and decay of plants like those of the Gulf Weed over a submerged region. Certainly, no such condition could be appealed to in explanation of the origin of the concretionary deposits under consideration, nor would it bring us any nearer to the origin of the material to attribute it to the denudation of deposits in pre-existing Palæozoic rocks, such as are known to occur in Estremadura. All the phosphoric acid must be

supposed to have been derived originally from the destruction of volcanic rocks and then extracted from the water by various organisms in precisely the same way as carbonate of lime and other substances are assimilated.

What these organisms are, has not, however, been satisfactorily determined. Many animals, no doubt, would yield on decay an appreciable amount of phosphates, if the material could accumulate tranquilly on the sea-bed, and infiltrate into limestone; but all these beds give more or less complete evidence of being formed in shallow or comparatively shallow water; and it has been urged that these are the positions where marine plants, which contain much phosphoric acid in the ash, most abound. Being rooted to the ground or growing over a definite area, they would tend to accumulate during a long interval of geological time a considerable quantity of phosphates, such as could be derived from no other source. These submarine forests are, moreover, the chosen feeding-grounds alike of herbivorous and carnivorous animals, and the phosphates set free would all be capable of combining with lime, and would thus explain the accumulation over limited areas of such beds of phosphatic nodules.

Salt and Gypsum.

The origin of rock salt from evaporation of the ocean and salt lakes is sufficiently obvious to need no detailed exposition; but Mr. Darwin and Mr. David Forbes have described in South America many beds in which, owing to the action of vegetation, other substances have been formed. There are great deposits of nitrate of soda, as well as horizontal layers of gypsum. The nitrate beds generally contain salt, and the nitrate forms from 20 to 75 per cent. of the bed. In drought, most of the streams of the Pampas become saline, and at Bahia Blanca the surface is covered for a quarter of an inch with a deposit that consists of 93 per cent. of sulphate of soda, and 7 per cent. of common salt. In many of the natural salt lakes near the Rio Negro, the salt is associated with crystals of selenite and sulphate of soda. There is seen to be every phase of change from chloride of sodium into sulphate of soda, and from sulphate of soda into sulphate of lime, the latter substance being developed wherever shells were sufficiently abundant to furnish the requisite lime, and the waters sufficiently sulphurous. There can, however, be no doubt but that the isolated crystals of selenite, common in all our clays, result from the decay by oxidation of iron pyrites, so that the liberated sulphuric acid combines with the lime of shells. But the great deposits in the Trias of Nottingham, Stafford, and Cheshire, which are often associated with rock salt, require such an explanation as is suggested by Mr. Darwin's observations.

Limestones.

Though many ancient limestones have obviously been partly reconstructed out of older deposits, yet every limestone deposit must be

regarded as separated from the water in which the carbonate of lime was originally dissolved. The distinction into fresh-water and marine limestones is not of much importance, though the fresh-water strata are probably more largely due to the precipitation of lime by the growth of plants, like Chara, than to the agency of mollusca and other kinds of animal life, which form so large a part of marine deposits. The carbonate of lime of limestone sometimes exists in the crystalline form of calcite, sometimes in the form of aragonite, and many shells have one layer of calcite, and the other layer of aragonite. There is no means known by which calcite can be changed into aragonite, the former being a remarkably stable substance, but aragonite is as strikingly unstable. When its temperature is raised it passes into a mass of crystals of calcite; it is also easily dissolved, and since calcite is usually deposited from cold solutions of carbonate of lime, it happens that organisms formed of aragonite are often removed entirely from a deposit, or replaced by structureless calcite. This difference explains not only the circumstance of preservation of many groups of fossils, but also important points in the general structure of limestones.[1] The following table may be useful in explaining the chemical condition of the shelly skeletons of the chief groups of fossils:—

Aragonite Organisms.	Calcite Organisms.
Cephalopoda are aragonite.	*Brachiopoda* are all calcite.
Gasteropoda are mostly aragonite; but *Patella*, *Fusus*, *Litorina*, *Purpura*, have the outer layer calcite.	*Annelida* are calcite.
Lamellibranchida are mostly aragonite, but *Ostrea* and *Pecten* calcite; *Pinna*, *Mytilus*, *Spondylus*, outer layer calcite.	*Crustacea* are calcite.
Hydrozoa millepora, mainly aragonite.	*Echinodermata* are calcite.
Actinozoa, almost wholly aragonite.	*Polyzoa* are a mixture of calcite and aragonite.
	Alcyonaria, calcareous forms are calcite.
	Foraminifera, calcite.
	Corallines, mainly calcite.

All marine limestones are formed from the remains of these organisms, or by chemical precipitation and deposition.

Of late years it has been demonstrated that everywhere throughout the deep ocean a white limestone is accumulating which, when dried, presents the consistency and appearance of white chalk. In the Atlantic this white globigerina ooze, as it is termed, consists almost entirely of shells of such Foraminifera as Globigerina, Pulvinulina, and Orbulina, mostly entire, with some otolites of fishes, and the mutilated dead shells of half-a-dozen genera of pteropods. With these are associated a small proportion of finer material which consists of the structures termed coccoliths and rhabdoliths,[2] with a few spines and skeletons of the silicious radiolarians, and fragments of spiculæ of sponges. Besides the surface forms of Foraminifera, Cristellarian and Milioline[3] forms occur which lived among the ooze, together with sponges, corals, starfishes, the higher invertebrata, and a few fishes. Below the surface layer thus composed is a somewhat firmer layer,

[1] Sorby, Brit. Assoc. Reports, 1862, Sect., p. 95.
[2] Wyville Thomson, "Challenger" Voyage in the Atlantic.
[3] Carpenter's Foraminifera, Ray Society, 1862.

an inch or two thick, with the shells more or less broken up and cemented into a calcareous paste, while beneath this bed the deposit is a nearly uniform paste, with only a few shells and fragments scattered through it. Thus it is evident that changes obliterating many of the more delicate organisms are rapidly brought about in such a limestone as is now forming on the floor of the Atlantic. Where the deposit becomes impure, as in the Mediterranean, it is yellow.

In contrast to such a deep ocean deposit is the white granular limestone forming the Bermuda Islands. This substance consists of coral sand, often cemented into a rock which can be polished. It is produced entirely by the wind, and may show from wind action only, according to Sir Wyville Thomson, in a short distance, appearances which resemble all forms of denudation and unconformity, as well as anticlinal and synclinal folds. These æolian rocks exhibit most regular stratification, and at Elbow Bay there is, what has been termed, a sand glacier, about twenty-five feet thick, which has come in from the beach, filled up a valley, and is steadily progressing inland. This limestone is full of caves, hollowed out by running water, or by the sea. One of these caves, called the Painter's Vale, contains a lake through which stalagmites rise up sometimes in pinnacles, sometimes in fringes, while from the roof innumerable stalactites several yards long descend and taper to points like knitting-needles.

Coral islands are a well-known example of limestone masses, built up partly by the direct agency of organic growth, and partly by the power of the waves to grind the coral into sand. Mr. Darwin has described the margin of a coral island as largely formed by great masses of the coral Porites, which are irregularly rounded, from four to eight feet broad, and parted from each other by crooked channels about six feet deep. As the coral extends upward it spreads laterally, so that many of the masses terminate upward in broad flat summits, where the corals are dead. Next in importance is the genus Millepora, which grows in thick vertical plates, so intersecting as to form a strong mass, like a honeycomb. In some reefs the brainstone coral, Meandrina, abounds. Other stony corals live at a depth of a few fathoms, and in the lagoon are thin, branching, and brittle corals of other kinds. The water outside a reef deepens gradually to twenty-five fathoms. At less than ten fathoms the surface is rugged when not covered with sand, but below twenty fathoms, coral sand is always met with. On the margin of the reef are three kinds of nullipores, extending as a fringe about twenty yards wide, and a few feet higher than other parts of the reef. One of these grows in expanded masses, like certain lichens on trees, another has a radiating structure, and is made up of stony joints as thick as a man's finger; and the third is reticulated, and formed of branches no thicker than crow-quills. These nullipores and the coral sand are cast up and cemented together by the evaporation of the sea-water. The rolled fragments often form islets, and as the channels are filled up, the surface of the reef becomes a smooth hard floor, as though composed of ordinary limestone. It is this flat surface, from one to three hundred yards wide, which the nullipore margins. It is

exposed to the sun at low water, and thus hardened by chemical precipitation. Hence coral limestone is far from being formed by corals only, and at some depth the cavities in the corals themselves are always obliterated by carbonate of lime deposited in them by infiltrating waters.

Remarkable calcareous deposits of small extent sometimes occur on land. Dr. Phené[1] has described a deposit of carbonate of lime which has buried up the Roman city of Hierapolis in Anatolia, and covered a large extent of country. Under the most eccentric and beautiful forms half the city is submerged by a mass of intensely hard rock which blocks up streets, temples, and arches. After reaching the level of its source it ran over the natural aqueducts which it formed as it went, only to begin and build up newer ones from a lower level. Six or eight of these walls occur, each nearly fifty feet in height, showing that many hundred feet of deposit have taken place since the Roman occupation. Part of the rock is perfectly white, having the aspect of drifted snow and frozen cascades. Other parts of it are as perfectly black. This is an example of the way in which springs such as have formed the deposits of travertine in many parts of Italy and the Auvergne may contribute to form limestones on land; while if the

Fig. 42.—Deposit of Travertin at a Cascade.

spring had flowed into a lake the deposit might have been more evenly spread, but would probably not have been less in amount.

On the shores of the Bahamas, the rocks are a hardened deposit of fine calcareous mud, but in some can be detected fragments of corallines, corals, mollusca, and foraminifera. In all seas the mollusca contribute largely to the formation of limestones, not merely by the accumulation of shell-beds but by becoming disintegrated and broken up—a condition which may result either from the mechanical action of currents or from decomposition when the organic substance which bound their particles together is removed.

Some shells like Pinna and Inoceramus are chiefly composed of minute prisms, which may be set free as fibres when the organic matter of the shell is lost. Similarly encrinites and all echinoderms fall to

[1] Brit. Assoc. Reports, 1879, Sect., p. 344.

pieces when the animal matter disappears, but the separate joints or plates are rarely minute; and sometimes, as in the mountain limestone, form a rock in which the eye can easily distinguish the component materials by the calcite cleavage.

Several recent limestones, like those of Bahama and Bermuda, contain oolitic grains. They have the aspect of having been formed in water containing mud derived from corals and decayed shells, but they are essentially chemical deposits, and show a granular texture in some grains and a crystalline texture in others. Thus, all the types of limestone which are met with in the strata are recognised as being in process of formation at the present day, and the following short account of the limestones as observed under the microscope by Dr. Sorby[1] will sufficiently demonstrate the conditions under which they severally came into existence.

The **Bala Limestone** is one of the oldest of British limestones. As typically seen, it consists almost wholly of entire joints of an encrinite embedded in fine-grained material which is for the most part made up of mica or chlorite, such as is found in the associated slates. Locally, it is oolitic.

The **Wenlock Limestone** is chiefly formed of more or less comminuted encrinites, with fragments of corals, bryozoa, brachiopods, and trilobites. Near Malvern, oolitic grains are sometimes found in this rock; and in the finer-grained beds Entomostraca are common.

The **Aymestry Limestone** and calcareous beds in the Ludlow rocks are essentially similar in composition, except that fragments of brachiopod shells are more abundant, and there are occasionally portions of bone, probably fish.

The **Devonian Limestones**, seen at Ilfracombe, Torquay, and Plymouth, are chiefly composed of joints of encrinites and fragments of coral. The fragments of brachiopod and other shells are much rarer. As in the Silurian limestones, foraminifera are not met with. Sometimes the Devonian limestones are converted into dolomite.

The **Carboniferous Limestone.**—In the typical localities the greater part of this rock consists of joints of encrinites, sometimes entire, sometimes broken, associated with fragments of brachiopoda and foraminifera, which are often as abundant as in average specimens of chalk. Recognisable fragments of corals and polyzoa are found, and sometimes shell prisms occur in great quantity. Occasionally coprolites, teeth, and fragments of bone form not unimportant constituents of the rock. At Bristol and other places some of the beds are oolitic. In Derbyshire and elsewhere some beds are changed into almost pure dolomite, but the organisms give no proof that the rock consisted originally of magnesia to any appreciable extent.

Magnesian Limestone.—Many beds originally contained oolitic grains and shell fragments; and such beds have exactly the structure that would be developed in an oolitic rock, if it became crystalline, by having half of its lime replaced by magnesia. The bulk of the

[1] Address, Quart. Jour. Geol. Soc., vol. xxxv. p. 77, &c.

rock has the beds consisting of large and small crystals with occasional altered shells of Foraminifera and Entomostraca. It is hence evident that the change has been brought about by infiltrating waters.

Lias.—Lias limestones chiefly consist of joints of Pentacrinus, often with fragments of brachiopods, oysters, and shell prisms, with some Foraminifera and fibres of belemnites. Finer beds are almost free from Pentacrinites, and are made up of fine shell sand and decayed shells. Grains of glauconite occasionally occur.

Oolites.—A large proportion of the oolitic limestones consist of fragments of echinoderms, oysters, brachiopods, and shell prisms; and, as compared with older rocks, contain an unusual amount of comminuted aragonite organisms mixed with rounded oolitic pellets, formed by chemical precipitation round nuclei. The ferruginous oolitic grains of Dundry have an unusually concentric structure. They were often broken during their formation, and the fragments became the nuclei for fresh grains. The fissile condition of the Stonesfield slate is to a large extent due to small and thin laminæ derived from the shells of oysters and brachiopods. In many cases the grains in the Great Oolite show a structure which suggests that they were originally formed of aragonite in concentric layers, and were afterwards changed into calcite.

The Forest Marble consists to an unusual extent of fragments of Terebratulæ, though larger parts of the rocks are made up of echinoderm fragments. At Bath it is chiefly comminuted oysters, and at Frome triturated corals and polyzoa. In some beds oolitic grains are abundant. The Cornbrash in Yorkshire sometimes includes vast numbers of small flat crystals of carbonate of iron. The oolitic grains of the Kelloway rock have generally recrystallised into fibrous calcite.

The Coralline Oolite is chiefly formed of broken calcite shells, of echinoderms, Ostrea, Perna, Mytilus, Serpula, and brachiopods. Some beds are chiefly formed of the shells of Renulina, others of aragonite corals. Certain of the oolitic grains have for nuclei grains of quartz.

In the Portland Oolite, the building stone is a shell sand varying in fineness, and mixed with oolitic pellets formed of fine granules (due to decayed shells) cemented together in grains which have a radiate structure.

The **Purbeck Limestones** are sometimes shell sand, chiefly derived from aragonite shells; often they abound in entomostraca, and frequently contain a large number of imperfect oolitic grains mixed with shell mud.

The **Wealden Limestones** are chiefly composed of fragments of fresh-water shells with entomostraca, and occasional pieces of bone, and in some beds laminæ of oyster shells.

The **Kentish Rag** in Kent consists of shell sand and shell mud mixed with quartz sand and other impurities. Glauconite abounds. Foraminifera are found sparingly, and there are some oolitic grains derived without doubt from denudation of oolitic rocks.

In the Firestone there is some volcanic ash.

Chalk.—Unbroken foraminifera make up but a small part of the Chalk, and all the fragments of these organisms together would not make up half the bulk of the rock. Prisms from the shells of Inoceramus, portions of Ostrea, Pecten, polyzoa, and echinoderms are abundant, as are spines and spiculæ of sponges. Fragments of brachiopods are rare. Coccoliths abound. In some localities there is abundance of fine quartz sand. In the soft Upper Chalk the cells of the Foraminifera are empty, in the hard chalk of Yorkshire they are filled with calcite.

The Tertiary limestones in this country are mostly fresh-water deposits, and limited to the Isle of Wight; unless we except the marine bryozoa limestones of the Coralline Crag in Suffolk.

Flints.

Flints are concretions of silica which have been accumulated in the strata, after their consolidation, by the solvent action of percolating waters, which have dissolved the substance of various minute skeletons of silicious organisms, and re-deposited the material. The chief accumulations of flint are met with in the Carboniferous Limestone, in the Portland and Purbeck beds, and in the Chalk. It is probable, in some cases, that no small amount of this silicious material has actually been derived from the solution of overlying sandstones, which have happened to contain sufficient lime to render the silica soluble. In the Carboniferous Limestone, the whole substance of the rock is sometimes removed and replaced by flint or chert, which exhibits cavities formerly occupied by fossils. In the Portland beds, the black flint is sometimes found in horizontal, sometimes in inclined fissures; and it frequently fills the interior of certain fossils, such as the *Cardium dissimile.* In the Upper Greensand of Warminster, and the Greensand of Black Down, the substance of many shells has been completely replaced by silica, and this condition is often met with in the Thanet Sands and other deposits. The most typical exhibition of flints, however, is furnished by the Chalk. The amount of flint in the Chalk varies with the locality, and is nowhere more remarkable than in the neighbourhood of Axmouth and Beer Head, though the individual flints are relatively small. Their number is, however, so great as sometimes almost to obliterate the appearance of arrangement in horizontal layers. Though chiefly characteristic of the Upper Chalk, flints are not exclusively limited to it, but they never occur in bands of nodules in the Lower Chalk. The size of the nodule, and the distance apart of the horizontal layers, which mark stratification, are extremely variable. The nodules themselves are of very irregular form, always white on the external or growing surface, where it is in contact with the chalk, and black or blackish in the interior. They are well developed in the Chalk of Norfolk, and the softness of the chalk is usually in proportion to the development of flint nodules.

Near London the nature of flints may be easily studied in the chalk

pits of Charlton, Grays, Gravesend, and Caterham. Sometimes, as in the neighbourhood of Leatherhead, the nodular flints have become subsequently cemented together, and embraced in horizontal tabular masses of flint. Another mode of occurrence of this substance is seen in the chalk of Norfolk and of Antrim, where subcylindrical vertical masses, like sacks of flour or sugar, are piled one above the other. These vertical flints are commonly called "pot-stones," because as they stand up on the beach near Cromer, they exhibit a tubular or pot-like appearance. This form is nowhere better seen than at Horstead, near Norwich, where the flints extend all round the pit in vertical columns, which pass through the horizontal layers of nodules. Sometimes the external surface is smooth, sometimes nodular and irregular. Each flint varies in height from one to five feet, and is usually a foot or two in diameter.

A third mode of occurrence of flint is well seen on the coast of Sussex near Rottingdean, where fissures in the Chalk are filled with tabulæ of black flint, which are inclined to the stratification, and sometimes pass through layers of nodules.

The formation of flint has generally been attributed to the growth, at the time the Chalk was forming, of organisms having a silicious skeleton, such as Diatomaceæ, Polycystinæ, and sponges. The flint in fissures, like a multitude of other phenomena, demonstrates that its accumulation in the forms now seen is of later date than the consolidation of the Chalk. In fact, flints in chalk have grown like septaria in clays. The material was there from the first, diffused in the rock, but it has taken all subsequent time for it to assume its present conditions of aggregation. Dr. Carpenter, impressed with the way in which sponges, like Holtenia, radiate their silicious roots into the calcareous mud of the ocean in a cylindrical figure, has suggested that the accumulation of silica from the growth of successive generations of sponges, one above another, on the same spot, might account for the nucleus around which the silica of pot-stones became aggregated. At the present day the chalk mud of the deep ocean includes in some localities from twenty to thirty or forty per cent. of silica, chiefly due to the accumulation on the bottom of silicious skeletons which fall from the surface; and therefore, unless they were especially abundant at particular periods of time, the horizontal layers of nodules would have to be attributed mainly to a similar extraordinary development of sponges on the ocean floor, for unless the silicious matter had been deposited more freely in certain beds of chalk than in others, it would have been impossible for the diffused flint in the Chalk to have gathered about nuclei in the way observed in the horizontal layers. Dr. Wallich believes that the flint was accumulated in the protoplasm of sponges, but there is no evidence to confirm this view. It may, however, be remarked that the Upper Chalk of Yorkshire which contains no flints has in it twice as much silica as the middle or flint-bearing Chalk. Flint may occur sporadically, investing organisms of all kinds, or even in internal cavities of teeth into which no organisms could have penetrated.

CHAPTER VIII.

CORAL REEFS.

From a very early period in the history of stratified formations, coral reefs have been formed in the old seas; but there is now no evidence to demonstrate the conditions under which those corals flourished. It is quite possible that the extinct forms may have known no limitation of depth or of temperature such as influence the distribution of existing reef-building corals. It is even possible that they may have been able to withstand the influence of muddy waters, so fatal to the animals forming coral growths at the present day. In any case, it would be unsafe to infer that the old forms of coral life were governed by laws similar to those which now influence the group, in face of the evidence that the generic types have in the long lapse of geological time undergone considerable modification of structure, as well as change in geographical distribution. The simple form of coral is not limited in its distribution by depth of sea; and some species live off our own coasts and far north, as well as in the tropics. And since the compound form of coral is a consequence of the fact that the polyps increase by buds which rise from the margin of the parent cup, and thus grow into a dense mass, it must be regarded as a geographical accident resulting from the distribution of land and water that reef-building corals are now almost entirely confined to the tropics.

In its simplest form, the coral is closely allied to the sea anemone, and in fact differs essentially from the latter in possessing a skeleton within the base and tubular investing substance which usually sends converging plates towards the centre, which correspond to the radiating partitions of the sea anemone called septa. In both groups the tentacles, which when expanded give the flower-like appearance to the polyp, remain uncalcified, and form soft fleshy substance. Some of these simple corals, such as the mushroom-like forms of *Fungia*, attain a considerable size; and such simple forms, represented by genera like Paleocyclus and Petraia, occur in the Silurian and Cambrian rocks. Considerable beds of limestone formed of corals are found in the Palæozoic strata.

Rocks formed of Corals.—Corals found fossilised do not appear to have formed accumulations of a thickness to be compared with existing coral reefs, but to have grown more after the manner of corals which occur around the shore of a rising or stationary land. The oldest

British limestone largely formed of corals is the Wenlock limestone; and here the formation is composed largely of starlike corals of the genera Heliolites, Favosites, and Cœnites, together with several which form more or less expanded masses, such as Syringopora and Halysites, Arachnophyllum and Syringophyllum. Again, in the middle of the Devonian formation, the Plymouth limestone often consists to a large extent of corals, among which are many genera, such as Favosites and Heliolites, which first appeared in the Wenlock limestone, with the addition of new forms, such as Smithia, &c. In the Carboniferous Limestone, especially in parts of Derbyshire, corals have accumulated so as to build up a considerable thickness of rock. Among these are the genera Nematophyllum, Stylaxis, Strombodes, Likoshotia, Cyathophyllum, and Michelenia. In the Secondary strata, especially of this country, corals of a compound type are less numerous; and although they have been met with in isolated masses in the Lias, Inferior and Great Oolite, it is only in the Coral Rag that limestone has been formed by their growth and from material derived from corals worn up by the sea. And similarly in the British Tertiary rocks there seems to have been no period during which corals formed reefs, although in the newer beds of the Lower Tertiary series, several examples of compound corals are found.

In existing seas, the most northern point at which reef-building corals live is the Bermuda Islands, which lie in the direct course of the Gulf Stream, and, therefore, in water warmer than is usual in that latitude. But, speaking generally, reef-building corals range between nearly 30° north of the equator and about 25° south of it. They are considered by Professor Dana[1] to die when the temperature of the sea falls below 66°, and they are not found alive at a greater depth than twenty-five fathoms. This depth they reach at the equator, probably because the water there at that depth is warmed to the temperature necessary to their existence.

All the coral reefs of the world belong to one type, but they have been classified by Mr. Darwin[2] for convenience in illustrating questions of movements of the earth's crust into three groups, which he names fringing reefs, barrier reefs, and atolls.

The **Fringing Reef**, under certain circumstances of depression of land, may in time become converted first into a barrier reef, and at last may take the form of an atoll; so that no broad distinction can be drawn between these forms of reefs, which succeed each other in much such a way as childhood passes into youth, and youth into manhood. The fringing reefs are so named, because they grow as a fringe around the shore, usually in shallow water where the sea-bed slopes at a slight angle. They grow at varying distances from the coast, which depends upon depth and the amount of sediment derived by tidal waters from the shore. The reefs are usually laid more or less bare at low water, when the bright-coloured red or green living animals are seen to rise just out of the water like a mud bank, through which numerous channels of water extend to the ocean.

[1] Coral Islands. [2] Coral Reefs.

Fringing reefs are formed of exactly the same genera of corals as the barrier reefs and atolls. The reef may be from 250 to 500 yards wide. The most common corals forming the reefs belong to the genera Porites, Millipora, Pocillipora, and the brainstone coral Meandrina.

Fringing reefs are met with at both ends of the Red Sea, on both the Arabian and African shores. They extend all down the Zanzibar coast and the coast of Mozambique. They surround the Seychelle Islands and the Mauritius, and occur round the north-east and south-west shores of Madagascar. They occur on the steeper shores of Ceylon, and round the Nicobar Islands, and are prolonged on the southern coast of Sumatra, and occur along the whole of the chain of volcanic islands which ends with Timor. Fringing reefs occur between Borneo and Malacca, around the Loochoo Islands, among the Philippines, southward to Ceram. The Mariana Isles have fringing reefs, as have the Solomon Isles, the New Hebrides, the Friendly and Navigator Isles; and the Sandwich Islands are thus margined. Fringing reefs also more or less surround nearly the whole of the West Indian Islands, and form a southern prolongation of Florida. Coral reefs are, however, entirely absent from the Pacific Coast of America, and are rare on the coast of Asia, east of the Persian Gulf. Thus it will be seen that with the exception of the reefs on the African coast, they almost all occur around islands, and especially on eastern coasts of the great masses of land. The fringing reefs appear usually to grow on shores which are either stationary, or which in comparatively recent times have been upheaved. Thus in Florida, reefs are found extending inland, exactly similar to those which are now forming on the shores; and from these the late Louis Agassiz[1] endeavoured to estimate the period during which the reefs must have been growing from the known rate of increase of the corals on the Florida coast. He considered the existence of these inland reefs to represent duration of time, equivalent to many millions of years. But the rate at which corals increase varies with the species and in different seas.

In the Red Sea, where the temperature is extremely high, never falling below 70°, and often rising to 120°, the coral grows so slowly, that its rate of increase is almost imperceptible. On the coast of the United States and in other places corals have been taken up from year to year, and measured and been found on an average to grow about half an inch in twelve months. But in one case where coral has grown upon the sunken British ship the "Shannon," it was found that supposing the coral to have commenced growing as soon as the ship reached the bottom, it could not have increased at a slower rate than three inches in a year. This coral belonged to one of the more open branching types of the genus Madripora. In other cases corals were planted on the coast of Madagascar, which in six months appear to have reached a height of nearly three feet; and it is recorded that a ship which had been in the

[1] Agassiz, Natural History Studies.

Persian Gulf for twenty months had a growth of coral on her copper bottom two feet thick. When living on the reef, the corals flourish best in the waters most exposed to the waves.

The **Barrier Reef** only differs from the fringing reef in the circumstance that the land near which it grows has sunk or become depressed to a considerable extent, so that instead of coming within half a mile or a mile or two of the shore, as the rule is with fringing reefs, it is usually at a distance of ten or twenty miles, or in some cases even fifty miles from land. Barrier reefs occur in the middle part of the Red Sea; and like the fringing reefs on the African and Arabian shores, they surround islands like the Comora Isles in the Mozambique Channel, and the Pelew Isles; they extend over considerable areas in the Pacific, notably forming the great barrier reef on the north-east coast of Australia, and extend round New Caledonia, some of the Fiji Islands, and the Society Islands. New Caledonia has one of the most instructive of barrier reefs. It is 400 miles long, and has an average distance from land of about ten miles. The island of New Caledonia is 250 miles long; so that we are led to the conclusion that New Caledonia has become by depression of the sea-bed 150 miles shorter since coral first began to grow around it in the form of fringing reef.

The Australian barrier reef, which extends for 1100 miles, is usually about twenty miles from the shore, though sometimes the distance increases to fifty or ninety miles. The depth of this channel varies from as little as fifty or sixty feet to as much as sixty fathoms in its southern part, where it is at the greatest distance from land.

Atoll is the name given to the reef when the land around which the coral grows has become completely submerged, so that the spot where it existed is only marked by the circle of coral which grew up to the surface of the sea as the depression progressed. This ring is occasionally perfect and frequently broken into segments. These gaps are precisely similar to those observed in fringing, and barrier reefs where rivers flow into the sea and bring down fresh water and mud, which renders it impossible for coral to thrive in such positions; though gaps are sometimes met with where the cliffs furnish to the sea a large amount of mud. Hence it has been inferred by Mr. Darwin that breaks in the continuity of an atoll reef may generally be taken to indicate the positions at which the streams flowed into the sea which drained lands now entirely submerged in the ocean and buried under a crown of coral. As a rule, the reef grows upwards as fast as the sea-bed is submerged, but occasionally the depression is so comparatively rapid as to drown the coral. Atolls are chiefly met with in the Indian and Pacific Oceans. Among the former are the Laccadive and Maldive Islands, the Chagos Bank, and the Saya de Malha, which form a stretch of submerged land between India and the north of Madagascar. It is impossible not to recognise that such a group of islands before they were submerged may well have been higher, and have formed continuous land from Mozambique to the Malabar coast. Such a land would help materially to account for the African element

in the fauna of India. Keeling's Island is an atoll in the middle of the Indian Ocean, which may have some connection with the ancient continuity which existed between the Mazarine region of Eastern Africa and the Malay Archipelago. In the Pacific, the chief atolls are the Low Archipelago, Gilbert Islands, Marshall Islands, and Caroline Islands.[1]

It is thus seen that atolls extend in lines like fringing reefs and barrier reefs with which they alternate. If, then, fringing reefs occur chiefly in areas of upheaval and other reefs in areas of depression, the Pacific and Indian Oceans exhibit to us by these means corrugations of the ocean floor which are now in progress, insensible it may be in amount during the periods for which they have been observed, but obviously analogous to the changes of level, of which the strata and existing contours of land are demonstrative evidence. If the atolls exist in great synclinal folds which are in process of depression, the lands bordered by fringing reefs are as certainly in the position of great anticlinal folds undergoing upheaval. To the physical geologist the distribution of coral reefs in the strata presents an important factor in elucidating the relations of Land and Water while deposits were accumulating, especially in the Tertiary, Cretaceous, and Jurassic periods.

[1] See Map in Darwin's Coral Reefs.

CHAPTER IX.

COAST-LINES AND THEIR ORIGIN.

EVERY part of the earth which rises out of the sea is distinguished by its own peculiar outline. This outline, in which the ocean marks a definite level around the land, is the sea-coast. Its fantastic curves on some shores, and scarcely broken straight extent on other lands, are not a matter of accident; for the causes which raise islands from the sea, also determine the main directions in which the coasts run. Inlets, bays, channels, and headlands may have to be explained by discovering the courses of old rivers, or the work of rain, and the kinds of rocks exposed; but the coast line has been produced slowly at successive ages of the earth's history, and parts of it have from time to time been portions of lands of far different outline to those of existing continents and islands, though the ancient lands are now more or less destroyed and submerged.

Influence of Altitude.—Nothing perhaps will help so well to make intelligible the first and simplest law under which a coast line may change, as to take a map on which are drawn lines showing the course taken over the country by contours indicating levels at ever-increasing heights such as would be marked by the sea, if the land were submerged to that extent. Then the successive steps would be traced by which a large mass of land may become broken into islands, and the reason why the smaller islands are formed would be more or less clear, for the sea necessarily would cover the low land first. Similarly with the sea; lines which mark depths of increasing amount in hundreds of feet enable us to understand how islands may be enlarged, united together, and into continents, and have the course of their coast line changed, by being merely uplifted so that the sea drains off from regions which it once covered.

Wherever a coast line remains for some time unchanged in level, the wearing power of the tides will usually convert what had previously been a shelving shore into a sea-cliff. If, then, land is upheaved at intervals, with periods of pause during which no upheaval takes place, then inland cliffs will be formed which correspond to these intervals of rest. The position in which cliffs are produced is often governed by the way in which the layers of rock forming the country are arranged. This arrangement of the strata into hard beds and soft beds is accompanied by an inclination of the deposits technically called "dip." The sea acting upon deposits so inclined abrades and wears away the exposed

edges so as to undermine the rocks and convert them into precipices on the seashore which are called cliffs. But when the deposits shelve down gently into the water, there are no weak places in the single stratum exposed which make it easy for the sea to cut a way through the formation. Since the whole country, even in recent geological times, has been elevated from out of the ocean, terraces must inevitably have been produced inland in this way at successive heights, though in many cases the rounding influence of the action of rain has more or less modified and obliterated the earlier work of the sea. But, although dip and mineral structure may help to demonstrate the reason why some coasts are worn away so as to be bordered by steep sea-cliffs, such considerations give no insight into the origin of the outline of the country or the way in which a sea-coast became a part of its geological history.

North and West Britain.—In dealing with the British Islands, it is necessary to have before us a map of this country and the adjacent parts of Europe coloured geologically. It will then be seen that the prevalent direction of the land forming the northern part of Britain is not a matter of accident. The Hebrides, Shetland, and Orkney all run in a direction from south-west to north-east. The strata in the part of Scotland north of the Caledonian Canal have a similar direction. The larger mass between the Moray Firth and the Firth of Forth is also extended so as to be parallel to the Outer Hebrides, and this mass has the Grampians for its axis. The southern part of Scotland is similarly traversed by the Carrick, Moorfoot, and the Lammermoor Hills, the rocks forming which extend through the country south-west into Ireland. If now the direction of these strata be compared with the rocks forming the Dovrefeldt, which is the mountain axis of Norway, the Grampians will be seen to be but a southern prolongation of that range, and, followed on into the north-west of Ireland, the Mourne Mountains carry the chain still farther to the south-west. No one who compares the west coast of Scotland and the coast of Wales with the opposite coast of Ireland, can fail to see that the strata of the two islands were originally continuous, and that the Irish Sea and channels to the north and south have been hollowed out by some cause which has not interfered with the direction in which the strata extend. From a geological point of view, then, Great Britain and Ireland may be treated as though they were one land. Nor must it be forgotten that the moderate elevation of six hundred feet would unite them together as a tableland, and prolong the coast of Scotland in a north-east direction to within a few miles of the Norwegian coast. Any geological student looking at a map will see that this direction of the old Primary rocks forming these countries is a consequence of the way in which the rocks at an early period of geological history were thrown into folds so as to be elevated from out of the sea. Each of the long strips of land forming Scotland and the isles west and north occurs as a saddle-like fold of the rocks of the kind termed anticlinal. The narrow strips between the Firth of Forth and the Firth of Clyde, and between the Moray Firth and

the Firth of Lorne, are trough-like folds of the kind named synclinal. This is manifest at once from the fact that the regions of the firths are composed of basins of newer Primary rocks, while the intervening mountainous regions consist of the older Primary rocks from which the newer deposits have been worn away, if they were ever deposited upon them.

Scotland probably originated in the elevation of the Grampians, which were at first, as Professor Judd[1] has demonstrated, a chain of active volcanoes which poured out enormous quantities of angular fragments and sheets of lava during much of the Old Red Sandstone and Carboniferous periods. But it is unlikely that the folds which are now to be seen determining the direction in which the rocks of Scotland extend, were fully developed until the close of the Primary period, and all these folds appear to be a consequence of a great compressing force acting from the north-west towards the south-east. It would be a mistake, however, to speak of them as having formed Scotland at this early period, unless we remembered that Scotland was merely a portion—a south-western prolongation—of the Scandinavian land. Nor can we consider this folding of the rocks without bearing in mind that it is parallel to other ancient folds forming mountain chains near the eastern coast of North America, and that the bed of the Atlantic itself is thrown into mountain ridges, one of which extending from Rockall on the north-west of Scotland runs south-westward far beyond the Azores to the mouth of the Orinoco. Everything in geological history leads us to believe that the great folds of the earth's crust having once been made, undergo no important change in direction in the successive geological ages. They may be modified—chains which were high may sink beneath the ocean; they may be broken up by folds which cross them transversely, but the evidence of their existence endures in the contorted rocks, and we are thus aided in determining the relative antiquity of our shores. It is probable that the old land thus indicated was connected on the south with the region which is now Normandy and Brittany. The Cambrian rocks of Wicklow correspond with those of North Wales; the Carboniferous and Old Red Sandstone strata of South Wales, which run nearly east and west, are continuous with the corresponding rocks in the south of Ireland. There these deposits occupy folds which are alternate saddles and troughs similar to those which are prolonged farther south by the rocks of Somerset, Devon, and Cornwall, continuous with the folds of Belgium, and parallel to those of the North of France. But here the direction of the resistance to the compressing force has changed, and hence the strike of the strata is almost due east and west in the south, although the intermediate angles can be traced in Wales and the adjacent English counties sufficiently well to demonstrate that there is no conclusive reason for assigning a much later date to the southern than to the northern compressions. If the latter took place during the great elevation of land at the close of the Permian period, the former are not more recent

[1] Quart. Jour. Geol. Soc., vol. xxx. p. 289.

than the close of the Triassic age, when the central European land once more disappeared.

Mid-Britain.—At this period the rocks which form the greater part of South Britain were not even deposited in the ocean. They comprise the whole of the Secondary series newer than the Trias. These rocks are chiefly alternations of clay and limestone running through the country in a direction from north-east in Yorkshire to south-west in Dorsetshire; superimposed upon them in the south-east are the still newer deposits named Tertiary. If our attention be now turned to the northern part of England, it will be noticed that there is a great central axis called the Pennine Chain, which runs north and south. This, it will be observed, consists of Carboniferous rocks. Resting upon its western side are the newer Triassic strata, upon which in the south of Cheshire rests an outlying mass of the Lias. This little patch of Lias, like a similar patch in the valley of the Eden, is sufficient to show that that formation was once more widely spread in the West of England; while it may have been continuous with other patches of Lias in the north of Ireland and the Inner Hebrides. But we are more concerned with it, because it demonstrates that the synclinal fold of South Cheshire was produced after the Lias had been formed. But when we turn to the east of the Pennine Chain, the whole of the Secondary strata, up to the Chalk, will be found in sequence, all of them running north-east and south-west, and all dipping to the east. This eastern dip teaches us that the Pennine Chain, though originated after the Permian and before the Trias, and progressing up to the Cretaceous age, was elevated finally at some period more recent than the deposition of the Chalk. Therefore, after the Secondary rocks had all been deposited, this part of Europe continued to experience a compressing force acting from east and west, which threw the strata into north and south folds. It is easy to see that the outline of the country at that remote time was quite different from what it is now; indeed, if North Britain had then been formed, an annual waste of the cliffs during the long subsequent ages no more in amount than now goes on would have produced a perceptible effect on the outlines of the land. But between Flamborough Head and the Tees it may be noticed that all the Secondary rocks, instead of continuing their course to the north, bend round in the Vale of Pickering and the Yorkshire moorlands, striking almost due east. It is possible that this eastern bend is of newer date than the north-to-south extension, but in any case it must be attributed to a resistance in the north, such as would be created by a folded prolongation of the Scottish Hills towards the Norwegian country. It might at first sight be supposed that the narrow form of the north of England is due to this east-to-west squeezing, but an examination of a geological map will be enough to show us that although there were formed at this time several subordinate parallel folds in the north of Wales, yet that the adjacent coasts of Wales and Ireland form an anticlinal, which excludes the possibility of the Irish Sea having originated in a compression which depressed that region in the same manner as the North Sea was depressed.

South-East Britain.—Finally, in the south-west the Tertiary strata extend chiefly in an east-and-west direction, which the Wealden and Cretaceous rocks also share. The Wealden elevation, which, it will be noticed, extends across into France, is clearly of the same date as the folds termed the London and Hampshire basins. The clue to the period when those synclinal folds were formed is furnished by the newer strata in the Hampshire basin. These are chiefly lacustrine and estuarine deposits, showing that the land towards the middle of the Tertiary period was becoming more and more upheaved. Hence, since we know that upheaval only takes place as a consequence of the lateral compression of the rocks—that is to say, of the formation of folds in them—we are led to fix the middle Tertiary or Miocene period, during which much of Europe was in a state of dry land and the Alps were rising, as the age when the north-to-south compressions operated in the south-east of England. It will be observed upon the map that the east-to-west extension of these newer deposits is paralleled by the similar extension from west to east of the Primary deposits of the south of Ireland and west of England. Hence, the direction of the eastern folds seems to be attributable to the persistence of an underlying resisting mass of consolidated rock similar to that which determines the folds on the western side of the island. It is within the limits of possibility that the Dogger Bank and the Yorkshire moorlands may show, by their eastern extension, limits of this Miocene compression on the north. Thus the several portions of Great Britain have been formed gradually, and although we have only considered the main folds which influence the directions in which a coast extends, still the effect of these compressions is obvious in the great east-to-west extension of the southern part of the island, and in the manner already indicated in the north.

The Channel.—We should seek in vain for any evidence of a convulsion of the kind mentioned, which would account for the separation of Britain from the Continent. That problem is like the separation of Ireland from Britain, and requires to be studied along the coast and on the geological map, which demonstrates that the waters which divide these countries are rather analogous to the Bristol Channel, where it separates Wales from Devonshire, than such waters as the Moray Firth or the Firth of Forth. The difference between these inlets of the sea consists in the fact that the former exists in what was an anticlinal fold, while the latter occupy synclinal folds. This anticlinal fold between Wales and Ireland, and between the Isle of Wight or Kent and France, means of course that the intervening region was thrown into an elevation, which may never have risen from out of the water, but which was essentially a mountain; and by a well-known principle, familiar to all who know the shape and structure of hills among the old rocks, it has resulted that just where the deposits were most uplifted and stretched and cracked, there they were worn away with the greatest ease, and replaced by depressions. The English and Irish Channels are therefore valleys, which have been scooped out in consequence of being thrust up. The rocks thus exposed to the action, first of the sea and afterwards of the atmosphere,

were more easily worn away because they had been already bent and broken by stretching along the axis of their upward bend. The excavation was a gradual process. In the south-west the English Channel commenced to be formed at an early period. The Channel is deeper in that direction, and therefore presumably older. It is impossible to determine how much of the excavation has been accomplished by ordinary waste along sea-cliffs, as the land was raised so as to bring every portion of a valley successively under the power of the breakers, and how much may have been worn away during the long ages for which its whole area remained in the condition of dry land, and exposed to the action of rain and winds and frost and rivers. It is probable, however, that these two powers, alternating with each other, have widened the Channel slowly in the way in which we see it widening in parts at the present day, by the waste of cliffs when they are undermined by the sea, and sawn out into gulleys by the land-springs which pour over them. Perhaps the most instructive parts of our cliff scenery are those which show the intimate connection of the island with the continent. All along the south coast from the Straits of Dover to Cornwall, the rocks of South Britain and the opposite coast of France face each other as though cleft asunder.

But besides its direction, every shore presents the minor features of bays, inlets, cliffs, and capes, whose existence is only intelligible by help of a knowledge of the ways in which the several geological formations which make up the dry land have been accumulated, folded, and upheaved so that the edges of strata are exposed on the shores where land rises out of the sea.

Headlands.—This dependence of headlands upon geological formations is well exemplified in Flamborough Head, in the North and South Foreland, in the promontory of Beachy Head, and in Culver Cliff and the Needles at the east and west ends of the Isle of Wight. All these headlands consist of chalk, and although chalk may be worn away by the sea like any other formation, when acted upon by the grinding power of the breakers, it cannot be disintegrated and washed up into easily-transported sediment like the underlying and overlying sands and clays. Hence, since its removal is largely dependent upon the chemical power of water to dissolve the limestone and take it up into invisible suspension, the rock is more enduring than the associated deposits which rest upon it and which it covers. And being a thick, homogeneous formation, which often has its fore-shore defended with a barrier of flint derived from the waste of the Upper Chalk already destroyed, it happens that this formation juts out into the sea, while on each side of it the strata are excavated by tidal attrition into bays. Of such bays Sandown Bay and Compton Bay are familiar examples, due to the removal of the soft underlying strata below the Chalk.

But the sea is often admitted into the land without any regard to nature of the strata, simply because they happen to be bent down into a trough, part of which sinks below the sea-level. This is the case with the estuary of the Thames and the Southampton Water, both of which owe their existence chiefly to lying in synclinal folds,

though partly to the ease with which the sea could encroach on the loose clayey and sandy formations, when, owing to a different level of the land, circumstances were more favourable for its work of excavation. The most important class of inlets occupies the positions of what were formerly dome-shaped or anticlinal folds.

The Shore.—As a district became depressed and the sea admitted, every portion of the land must in succession have been a shore, and the shore moved gradually with the depression of the land to a level which was progressively higher. When we remember the power which the sea possesses of throwing up around our coast in stormy seasons not merely the spoils of life but masses of rock from great depths, a mechanism becomes discernible which has brought gravel beds and our pebble beaches gradually into their present position in times antecedent to the final shaping of the contours of the coasts. The beach follows the shore, and it may be that much of the material thus brought back again had previously been scoured from the present seaward slopes of the country in an antecedent age, when its level was higher. These materials are ever reinforced with the hard fragments worn from the nearest local source, and with pebbles driven along the shore by waves lashed by the wind. A remarkable instance, however, of the mode of origin of such pebble beds is furnished by the Chesil Bank, which stretches for about eleven miles on the Dorset sea-board from Portland to Abbotsbury. Portland Bill has arrested the movement of pebbles to the east like an artificial groin, but when their nature is examined, and the large size of the pebbles in the eastern end of the bank near Portland is considered, there is no sufficient reason for believing that they travelled out of Cornwall and Devon along the existing shores when the rocks of the floor of the English Channel could so easily have furnished an assemblage of this kind, which would equally have become embedded in the ledge of Kimmeridge Clay which forms the foundation of the bank, and there became heaped up as the land descended to its present position.[1] The same agencies which have brought the pebble beds to our shores have been chiefly concerned in the production of sea-cliffs. We know the rapid waste of certain parts of the coast, where noble strips of land have in historic times passed, often with towns and villages upon them, back into the sediments of which they were originally composed, and have been swept out over the floor of the German Ocean. But all our coasts happily do not crumble away like those of Yorkshire, and though the changes which take place from year to year prove that the existing aspect of many cliffs is of very recent origin, yet their geological structure often makes it probable, even when proof is wanting, that they too have come down to us from an immeasurably distant past. Some coasts are especially favourable to the formation of cliffs, because the rocks are hard and not easily worn away, while the land which they form rises to a fair height from the sea. Seaside towns generally occur where gaps appear between cliffs, though there are many exceptions. The gap furnishes a ready means of

[1] Prestwich on the Chesil Bank, Institute of Civil Engineers, vol. xl.

reaching the sea, and often owes its existence to a bed of clay which had been exposed down to a low level on that coast, and eaten back by the sea into a bay. This bay is usually a point from which the adjacent harder rocks may be undermined, for drained of the moisture they contained, owing to the dip of the strata, their substance contracts and becomes divided by innumerable cracks and division planes, separating into blocks which have no support or firm coherence with the mass of the stratum, when the underlying portion between tide-marks has been removed. After falling, these fragments, when hurled back by the tidal waters, become battering-rams for making further inroads into the sea-wall of rock, and thus the process goes on, governed by the direction of the wind and the currents which move the water. The height of a cliff is governed chiefly by the height of the adjacent land. On some parts of the west coast of Scotland, the height of cliffs is immense; and, as a rule, among the contorted and upheaved Primary formations cliffs are higher than among the newer formations. But the waste is less rapid, and the cliffs often show in their retreat from the shore, in their upper portions, evidence of denudation, and different relative positions of land and water to those which exist now. The Secondary rocks, from their loose texture, have wasted at a more rapid rate, and the cliffs are often high, because easily undermined, and so eaten back that the traces of earlier denudation have become obliterated. The Tertiary cliffs of the east and south-east of England are mostly of moderate height, because the level of these deposits rises so little out of the sea, as may be seen in the Crag formation at Felixstow and Aldborough, while on many parts of this coast of Suffolk cliffs have no existence.

Sand Dunes. — Though the sea thus destroys the coast, and forms cliffs, yet the winds often protect the shores where no cliffs exist. On sandy coasts, as the tide runs down, the sand left dry is caught up by the wind and blown inland, only to be arrested by vegetation stopping its movement at a little distance from the water. A mound thus formed becomes permeated and reticulated by the roots of those plants which specially luxuriate in these conditions, and year by year the mounds may grow in height until a ridge of hills, or sand dunes, often of considerable height, is formed guarding the shore. In our own country these sand hills are less developed than on flat continental coasts; but on some parts of Norfolk, South Wales, and Cornwall, good examples of sea-coast scenery of this kind may be seen. Sir Charles Lyell published a sketch of the church tower of Eccles in Norfolk covered up in a sand dune, as it appeared in 1839; but the winds which heap up the sand may reverse their direction, and in 1863, when we last visited this part of the British coast after unusually strong equinoctial gales which scoured all the cliffs clean in the north of Norfolk, every trace of the outer range of these sand dunes was gone. The church remained clean and roofless by the shore, the fields which had been newly ploughed before the sand had covered them were laid bare, as fresh as though the furrows were newly turned, even to showing the prints of the hoofs of asses which had drawn the small and primitive plough. Prior to the formation of the sand hills the waste

of the coast had been rapid, and their removal serves to show how potent a factor wind is in transforming coast scenery. Probably its importance inland is even greater.

Landslips.—Another feature of the coast which conspicuously affects the scenery in many parts of the south of England is the occurrence of landslips. Though not directly the work of the sea, they occur most frequently on the coast. When the strata happen to dip towards the sea, and some water-bearing sandy bed in a clay, or resting upon a clay, thoroughly moistens the underlying deposit so as to cause it to become slippery, then the weight of the superincumbent rock is often sufficient to break a strip of jointed rock away from the adjacent inland mass of the stratum, and cause it to slide into the sea, there to become broken up by the action of the waves. One of the largest of these landslips is that which from Ventnor to Blackgang forms the peculiar scenery of the Undercliff, caused by the water held by the Upper Greensand moistening the underlying Gault, so that Chalk and Upper Greensand have slipped away to the sea. Similar phenomena, formed in 1839, are to be seen west of Lyme Regis, near Axmouth.

Waste of Cliffs.—On the whole length of Holderness, the waste of the cliffs is not less than two and a quarter yards in breadth annually. The average loss on the coast of Norfolk between Weyburn and Sheringham is about one yard per annum; on the coast of Thanet two or three feet. But these same coasts likewise exhibit, on an equally grand scale, the formation of *new land* from the materials thus detached from the old. The materials which fall from the cliffs are sorted by the tide, and according to their bulk and weight are differently disposed of. As in many artificial processes of washing powders, the sediment is divided into parts of different fineness by merely shaking it at different distances or depths in the stream of water, so it is in the great currents of the sea. Large stones remain a long time at the foot of the cliff from which they fell, smaller masses yield something to the impetus of the waters, sand and pebbles are drifted along the shore according to the set of the tide, and collected into bays and hollows of the coast, or deposited in a line of moving beach; but the finer clays are transported far away in the waters, and allowed to settle only where these rest in land-locked gulfs, stagnate over weedy marshes, or lose their force in contest with the freshes. The breadth of the sandy beaches thus accumulated is often very great, even many miles of slow and regular descent. The sand banks which stretch out so far from the low coasts are often regarded as remains of ancient lands overwhelmed by the sea, but in most cases they are probably recent formations, accumulated by the waves from the spoils of other regions. But what is thus left by the sea under some circumstances, may be again reclaimed by it under others. The once fertile district called North Friesland, most probably accumulated by the sea, measuring from nine to eleven geographical miles from north to south, and six to eight from east to west, was in 1240 entirely severed from the Continent, and in part overwhelmed. The island of Northstrand, thus formed, was, towards the end of the

sixteenth century, only four geographical miles in circumference, but still was richly cultivated and populous. At last, in 1634, in one night, the 11th of October, a flood passed over the whole island, whereby one thousand three hundred houses, with many churches, were lost, fifty thousand head of cattle and above six thousand men perished. Three small isles alone remain, and they are still further wasting. It may often be remarked that substances thrown into the sea are not carried down at once to its depths, but rejected many times to the shore, in the direction of the tidal currents. This happens especially with all light, small, and easily moved bodies; but the case is different with the large blocks of stone, which, continually pressing by their weight downwards, are for the most part gradually withdrawn from the base of the cliff, sunk in the beach, and rolled down to the deep.

Islands.—Islands originate in very different ways. Most volcanic islands are, properly speaking, volcanoes, and have been upheaved out of the sea which surrounds them by the same forces as produce the volcanic eruption. Coral islands, or atolls, on the other hand, are rather examples of rock structures built up out of the sea by coral polyps than islands in the ordinary sense of the term. What is an island now, in the last geological age was probably a submarine shoal, and in the next age is likely to be part of a mountain axis. Hence it is that islands often occur in chains, when they are but the peaks of mountains rising from out of the sea. Or, they often terminate peninsulas, or lie contiguous to large masses of land, because some low pass is depressed beneath the sea-level, through which the sea flows, and severs the island from the adjacent land. Thus Tierra del Fuego is but a portion of the Andes, which does not run continuous with the rest of the chain, because it has not been upheaved so high. Even these continental islands, however, may be formed in various manners. It is comparatively rare for them to be the result of simple uplifting or depression of the sea-bed. Usually the rocks have been more or less folded and fractured; not unfrequently channels, deep or shallow, have been scooped in them by tidal action, or by ice, so that the sea has been able to surround the mass of land. The small islands around our own coast afford examples of the ways in which most of the islands of the world have been produced. Perhaps the simplest illustration of an island, which might result from depression on a small scale, is furnished by St. Michael's Mount near Penzance. There, when the tide goes down, a tiny isthmus is seen to connect the mount with the mainland, while at high tide all trace of union disappears. This method of the formation of islands can be studied fully on any map of Britain on which the levels of the high and low land are marked. For by means of the scale of colours or shading used, it may be observed how with varying degrees of depression, the sea would penetrate into the land, breaking it up into islands and islets.

Isle of Wight.—But a more instructive example is furnished by the Isle of Wight. This island has its chief extension from east

to west: it consists of the rocks which are called Cretaceous in the southern part, and in the north of those called Lower Tertiary lying upon them; all these deposits being more or less turned up on end. For the Isle of Wight forms the southern portion of a great trough or synclinal fold of the strata, which is known as the Hampshire Basin. And the middle portion occupied by the newest rocks comes precisely in the line of the sea now known as the Solent and Spithead. Over this depression an excavation has been worn. It is possible that it may have been originated by the River Avon and the Southampton River, at a time when the level of the land was somewhat higher; and then the sea, obtaining access to this shallow channel by a subsequent depression, probably widened it year by year at the expense of the adjacent land, until the comparatively broad water was formed which severs the Isle of Wight from England. On the southern coast at Brook, the Wealden beds are seen which correspond with the Wealden strata of Swanage Bay in Isle of Purbeck; and there can be no doubt but that the Chalk, and all the strata which lie beneath it at the western end of the Isle of Wight, were continuous with Dorsetshire when the uplifting first took place. It will be observed that, since the strata on the southern shores of the Island all dip to the north, the synclinal fold which forms the island might be prolonged up into the air southward of the Isle of Wight, so as to form an anticlinal fold south of it. Such an anticlinal fold, more or less complicated, inevitably existed when the island first began to be upheaved; but since rocks, of a brittle nature like chalk, are easily cracked along the direction in which they are bent, it must be concluded that the rocks became fractured along the axis of upheaval, and that the part of the anticlinal fold to the north of this fracture or "fault" was squeezed up out of the ocean, while the other or southern portion was excavated by denuding agents. Not that such fractures could have determined the southern outline of the island entirely, because that is to a large extent obviously attributable to the eroding action of the sea now going on; but that there are many indications of minor faults in the strata of the Isle of Purbeck; and it is probably owing to small parallel fractures which run through the island that the Upper Greensand between Ventnor and Blackgang has slipped down bodily towards the sea, so as to form the Undercliff. Thus the Isle of Wight must be considered to owe its existence partly to anticlinal and synclinal folds of the earth's crust, partly to fractures running through the rocks, and to denudation along these lines.

Isle of Man.—Other conspicuous islands are the Isle of Man and Anglesea. The Isle of Man consists chiefly of Upper Cambrian rocks, with a small mass of Carboniferous limestone in the south. This Upper Cambrian or Lower Silurian is obviously continuous with that of the Lake country of Cumberland and the opposite coast of Balbriggan in Ireland, and the island is an extension of that anticlinal fold towards the south-west, similar to the south-westerly extension of the Silurian rocks of Wigtown and Galloway towards

the opposite coast of County Down. Geographically the Isle of Man belongs to Cumberland and Lancashire, because an elevation of not more than a hundred feet would again join it to those counties. The shallow sea which severs it from the North of England has probably been ploughed out in part in comparatively recent times.

Anglesea.—The Isle of Anglesea is divided from Wales by a channel scarcely wider than a river; and it is not easy accurately to determine how the separation was effected; but Professor Ramsay has remarked that with the exception of Holyhead and Garn, the general level both of the island and of the opposite parts of Caernarvonshire is low, not rising more than two hundred feet above the sea. He observes that the rocks are smoothed with ice-marks, and scored with glacial striæ, which run towards the south-west; and that the country is covered with boulder clay full of angular fragments, such as a glacier would carry or deposit. These glaciers could not have originated in the mountains around Snowdon; and it is concluded from the rock fragments deposited that the glacier must have come from high land farther north — in fact, from Cumberland and the mountains about Criffell in the south of Scotland, probably at a period when the level of Britain was higher. A glacier of this large size would have passed between the coast of Cumberland and the Isle of Man. It not improbably scooped out the shallow sea between them. It received a tributary glacier coming down from Morecambe Bay; and passing over the whole of the Isle of Anglesea may have excavated the Menai Straits, as Professor Ramsay suggests. But since carboniferous limestone forms much of the shores of the Menai Straits, it is impossible not to suspect that, though filled with ice in a glacial period, this channel may have originated in times far more remote as a sort of cañon. Thus, both the Isle of Man and the Isle of Anglesea belong to a class of islands, of which the existence is directly attributable to denudation.

Lundy Isle.—A third group of islands may be typified by Lundy Island in the Bristol Channel and the group called the Channel Islands. These appear to owe their existence rather to the durability of the rock of which they consist—that is, to their greater power of resisting denudation—than to other causes. They are granite bosses similar to those which would remain at the Land's End, about Falmouth, St. Austel, Bodmin Moor, and Dartmoor, if the level of Cornwall and South Devon were to be lowered. They are without doubt indications of axes of upheaval. It is even possible, as suggested by Professor Judd in the case of Lundy Isle, that they may have been the central cores of old volcanoes; but it is also quite possible for granite to be formed by pressure in the axis of an anticlinal fold, and to cool there without ever bursting through the great thickness of over-lying rock which originally covered it. The attempts made by Mr. Sorby to estimate the pressure under which granite consolidated, would lead to the conclusion that denudation to an enormous extent, involving the removal of rocks

thicker perhaps than the height of the loftiest mountains of the world, must have taken place in the region of the English Channel before the granite cliffs of the little island of Sark could have been laid bare.

Inner Hebrides.—Finally, there are, in the Inner Hebrides, islands where the surfaces are portions of lava sheets poured out from volcanoes which themselves formed larger adjacent islands, or existed on the mainland. It is difficult to judge of the condition of the west coast of Scotland in those older or middle Tertiary times, when the lava streams were poured out. But not improbably the country was a tableland, and the lava flowed out under the atmosphere. The basalt of the Isle of Mull extends across into the opposite peninsula of Morvern on the one hand, and on the other side forms Ulva and Staffa; while the Treshnish Isles probably but imperfectly indicate its western extent. The lavas of Eigg may have been emitted from the volcano of Rum. Any one who examines this ancient British volcanic country, and observes the broad and deep channels which the streams excavate for themselves in it, will be at no loss to discover the means by which, aided by depression in level of the country, the sea severed islands like Ulva and Staffa from the adjacent land. A similar valley widened by the sea formed the Sound of Mull. This is almost demonstrated by the fact that the rivers and streamlets all run into the Sound of Mull at right angles to its length, just as though they were tributaries joining a larger stream. Hence these volcanic islands and islets have originated in denudation, and only differ from the other examples mentioned, in the fact that most of the rocks seen on their surface have been poured out in molten streams from cones of volcanoes, instead of being deposited as strata on the floor of the ocean.

It is instructive to observe that an elevation of fifty fathoms would remove the whole of the Malay Archipelago from the map, and substitute in its place a south-eastern extension of the Asiatic continent. It is even more instructive to remark the vast depths from which atolls in the Indian and Pacific Oceans rise from the sea-bed, since we thereby obtain an idea of the height of mountains which have sunk beneath the sea, and the probable area of lands which have been removed by the depression of islands, since the main outlines of land and water have been what they are now.

CHAPTER X.

THE GENERAL FEATURES OF SCENERY IN THEIR RELATIONS TO GEOLOGICAL PHENOMENA.

Tablelands and Low Plains.—When a submarine ridge is elevated so rapidly as to emerge from the ocean as a small island, tidal waters at

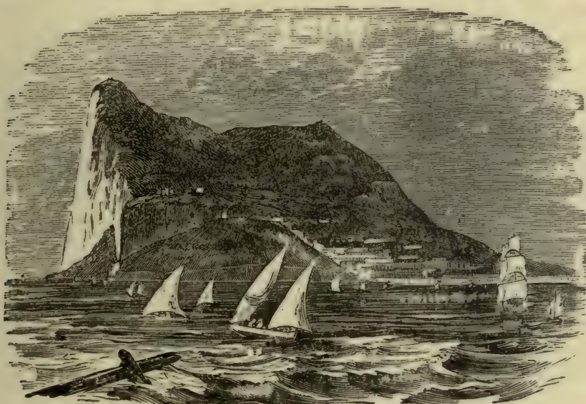


Fig. 43.—Gibraltar.

once begin to cut back the coasts and form cliffs; but, as the land rises higher and enlarges, other cliffs are cut below them, so as to present in succession all the steep descending slopes of mountain scenery. But when the upheaval is more slow, so that the sea can cut away the rock as fast as it is raised, then it does not rise from the water, but the surface is planed level beneath the water, and when it at last emerges, after losing from the uppermost strata in some cases thousands of feet, or it may be miles of thickness, presents itself as a plain of marine denudation. Such a plain is usually an anticlinal fold, or rather a series of folds of which one or more originally rose higher than the rest. Much of the surfaces of England and of Ireland were originally plains formed in this way. When such a plain, however, is uplifted high above the sea, it is termed a tableland, and what was an island is often thus enlarged into a continent. Once above the water, the sea erodes its shores into cliffs, and as these descend lower and lower with the increased elevation of the land, it inevitably

results that the tableland becomes surrounded by mountains. Sometimes one side rises faster than the other, and then—as in the tableland of Mexico, for instance—we find the Pacific side rising rapidly in a series of terraces, which indicate more or less stationary intervals, while the tableland slopes somewhat towards the Atlantic coast.

It is impossible to go into any part of the mountain scenery of Wales, or the other higher districts of Britain, without realising that the multitudinous peaks which occur at approximately the same level are but the last relics of a plain which was originally continuous between them; sometimes, indeed, a succession of plains descending one below another, may in this way be traced out by the eye. Yet so ancient was their origin, and so powerful have been the denuding agents acting upon them, that the mountains play the part of gigantic earth-pillars, such as are seen in Colorado or the Tyrol, and are the sole remaining points in tablelands which are now variously sculptured into valleys and hills.

Similarly the Secondary strata, which are less inclined than the Primary rocks, and but little folded, rest upon each other so as to form surfaces which are approximately plains, though the flocculent particles of the unhardened clays have been swept away so as to give them a lower level than the more enduring limestones and sandstones. The British Isles need but to be elevated some 600 or more feet to present the essential characteristics of tablelands. It will thus be clear that a tableland is a plain distinguished by its mode of origin, and is quite independent of height; for even where its level is relatively low, it is in all respects the antithesis of what is termed a low plain. It may be convenient here to put these characteristics in contrast, and say that a tableland is the oldest part of a land, while a low plain is the newest part of a land; a tableland is formed in a region of predominant anticlinal fold, while a low plain is formed in a synclinal fold; a tableland consists of such rocks as form the fundamental structure of the country, while low plains consist of detritus worn off from the higher ground and deposited at a lower level; tablelands are usually dry, relatively barren regions carrying their rivers in deep narrow valleys; low plains are the fruitful populous portions of the earth, carrying their rivers through valleys which are broad and shallow. No region exemplifies the relations of these phenomena better than South America.

A Tableland in the Andes.—High up in the Andes of Quito and of Bolivia we find the peaks of the mountains planed away, and a broad level surface presented; which, in the cases of Desaguardero, is upwards of 13,000 feet high and over 500 miles long. This tableland was described by Mr. David Forbes, F.R.S. Near Arica the mountains rise abruptly 3000 feet from the water's edge, and everywhere as we ascend there is evidence of emergence from the ocean, and evaporation of the sea, in the existence of deposits of salt. 1st. At a height of 2500 feet to 3500 feet, beds of nitrate of soda run from ten to forty miles inland. These beds were originally chloride of sodium decomposed by carbonate of lime into chloride of lime and carbonate of soda,

which in its turn has been decomposed by vegetation into nitrate of soda. 2d. At a height of 7000 feet to 8000 feet in the desert of Atacama, there are immense salt plains on a grand scale. 3d. At a height of 13,000 feet, on the tableland, white crystalline salt is found on the shores of swamps and lakes. This tableland is intersected by ranges of hills which run north and south, and sometimes rise 2500 feet above the plateau. The intervening valleys are nearly level plains often formed of gravel, resulting from the wearing down of the ridges. Volcanic cones occasionally rise 6000 feet above the plain. The area may be separated into west, central, and eastern parts, which are respectively of Oolitic, Permian, and Silurian age.

The Silurian rocks here form the higher chain of the Andes, rising to 25,000 feet, and extending through the ranges which feed by the melting of their snows tributaries of the Amazon and the La Plata. Farther south in Chili the structure of the country is somewhat different. In the north, mountains predominate, but in the south the mountains are

Fig. 44.—Pass (Andes).

subordinate to the plains. Mr. Darwin mentions that Santiago stands on a plain 15 miles broad, and 1750 feet high, which has the undulations of its surface parallel to the main valleys of the Andes, against which chain it abruptly terminates. The surface of the plain is formed of stratified pebbles, volcanic ashes, and clay. Southward it contracts and expands successively three or four times, forming a series of basins connected like a necklace. On the eastern side of the Andes, the mountains are abrupt, and rise out of a slope like a talus which is formed of rounded pebbles. This slope blends into a flat space 2700 feet above the sea, which is a few miles wide, and is bounded to the east by an escarpment 80 feet high, running north and south, and formed of rounded pebbles, obtained beyond all question by the sea from the Andes, and rolled and rounded at their base, when the higher tablelands had been so far raised from the sea as to connect these mountains into a long and narrow island. As the South American tablelands are followed northward into North America, their

level becomes lower, and the two parallel mountain-chains which border them diverge from each other so as to make the tableland broader.

It is almost impossible now to discover what share tablelands may have had in the ancient geological history of the British region; but it is not difficult to see from the present position of the outcrops, and from the manner in which deposits succeed each other, that the history of British scenery is mainly the history of tableland phenomena.

Low Plains.—There are, however, some formations which especially suggest low plains, and it may conduce to clearness if we briefly notice the typical characters of the low plains of South America. For since these sediments are so obviously the wreck and waste of the Andes, slowly worn into mud and sand as the mountains rose, they are typical of all plains which lie on the flanks of mountains, or in synclinal folds. The whole surface of the pampas still retains salt enough to render the streams saline in time of drought. Sometimes, as at Bahia Blanca, salt covers the country like hoar frost for a thickness of a quarter of an inch, and sometimes the sandstones are bound together with salt. The material of the pampas is a red earth or mud, which sometimes becomes compact marly rock. Pebbles are only found at the foot of the mountains, and between the mountains and the pampas mud the subsoil is sandy. Near Buenos Ayres the pampas mud is upwards of 200 feet thick. Such plains may be matched in Europe by the Russian steppes, the plains of Hungary, Lombardy, and in our own country by little areas like the Carse of Stirling. Though the fenland of Cambridgeshire is a plain, the deposits upon it are so thin that it can scarcely claim to be an example of a low plain. When, however, we look back in time, many formations suggest an origin like that of low plains, and among such may be mentioned the Coal Measures, and the various secondary and tertiary clays which yield the remains of land vegetation, or of terrestrial reptiles. It may perhaps be doubtful whether the land surface indicated by the Trias was low or high; but, widely spread over Europe, it must have been a plain, during its period of elevation, as conspicuous as any which marks the existing surface of the earth.

Lakes.—Nearly all the great lakes of the world owe their existence to direct upheaval of the ocean floor. If the English Channel were to be raised two or three hundred feet, a number of small lakes would extend along the deeper part of its bed. If Southern Europe were to be somewhat upheaved, then the Black Sea would be perfectly isolated from the Mediterranean. Similarly the Mediterranean might be separated from the Atlantic, and at the same time the level of the Mediterranean would be so far lowered by the draining off of the waters by the Straits of Gibraltar, that the shallow sea between Tunis and Italy would become dry, and the Adriatic would be surrounded by land. Thus, merely by elevation to the amount of a thousand feet, the Mediterranean might be converted into a chain of lakes. On the other hand, if the south of Europe were to be somewhat depressed,

then the lowland of Southern Russia, peopled by the Kirghis and the Cossacks of the Don, would be overflowed, and the Caspian Sea would become continuous with the Sea of Azov and the Black Sea. Since depression would cause the Caspian to cease to be a lake, it is an obvious inference that elevation severed it from the sea, of which it formerly formed part, by laying bare the shallow sea-bed, which is now largely occupied by salt marshes, and in part liable to inundations. In the same way it may be noticed that the Baltic is almost enclosed by land, and if elevation instead of depression of the country were now going on in the south of Sweden, the Baltic would inevitably be converted into a lake by a process of change in level, which need not necessarily affect a wide area. The great Russian lakes Ladoga and Onega are merely prolongations of the Gulf of Finland, leading northward to the White Sea, and are remains of a channel partly dried up.

Lakes Formed by Evaporation and Upheaval.—Consideration of the lakes of Central Asia, many of which are salt, and of broad areas occupied in Persia, Turkestan, and Northern India by salt marshes, helps to show how old the main outlines of the rocks are which form the physical features of the surface, relatively to the lakes which fill depressions among them; and also demonstrates how recent the last elevation of the country from the sea has been. All over the plains between the Caspian and the Sea of Aral, and between that sea and Lake Balkash, and thence on to Lake Baikal, deposits of shells are found, recent in aspect, some of which are similar to those which now live in the Caspian Sea. Lake Baikal, however, is a freshwater lake, yet it contains a large number of saltwater types of animals. Seals abound there similar to those which live in the Adriatic and the Caspian. Many saltwater types of fishes have representatives which thrive in its waters. Hence it may be concluded that Lake Baikal was originally a portion of the great Central Asian Sea, and was one of the deepest pools in its bed; and that it became, by elevation of the mountain axis of the old world, converted first into a saltwater lake, and afterwards into a freshwater lake. Some evidence in favour of this view exists in the fact that in the deep waters of Lake Superior some types of animals have been found which are otherwise only known in the sea. The question of a lake being salt or fresh depends entirely on the rainfall. When the amount of rainfall is in excess of the evaporation in the district, then the fresh water drains into the lake basin and dilutes the salt water; this diluted water overflows, and the stream carries some of the salt from the lake down to the sea. Thus, little by little, the salt is entirely removed, and what was originally a saltwater lake becomes a freshwater lake. It is probable that in most cases the change goes on more rapidly than happened in the case of Lake Baikal, and in consequence the marine life, unable to adapt itself to the altered conditions, perished; and it is only conceivable that the change to freshwater conditions in that lake occupied so many generations as to have had little influence on the lives of individual animals.

Lakes Formed by Folding of the Rocks.—A second group of

lakes has been produced as a consequence of compressions which have thrown the rocks into parallel folds on a smaller scale. Thus valleys have been formed and closed by tilting so as to have no outlet for the drainage. Lakes of this kind are usually situate among mountains, and probably no better examples could be taken than the lakes on the west coast of Scotland, or those of the Alps, which are ancient fiords closed by upheaval. No broad distinction can be drawn between such lakes as these and those of the former class, for both have originated in compressions of the earth's crust. Lakes like Neufchatel may have been fresh ever since the Alps attained their present elevation, although sea-birds still frequent the higher Alpine waters.

A third group of lakes is exemplified by some in Scotland, which have been described by the Duke of Argyll and others, in which the waters lie along anticlinal folds or saddles, and must be supposed to owe their existence to the ease with which an anticlinal fold was excavated by the sea when the level of the land was lower.

Excavated Lakes.—A fourth group of lakes would appear to have

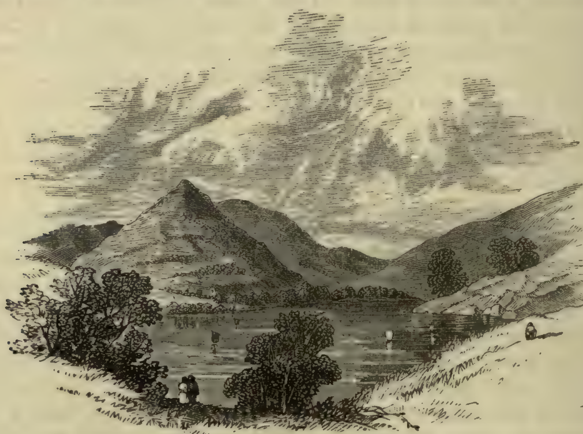


Fig. 45.—Helm Grag and Grasmere.

been excavated by the erosive power of glaciers, towards the close of the glacial period, when glaciers descended from all the principal mountains in our own country and Northern Europe. Some of these lakes, like those at the foot of Snowdon, and elsewhere in North Wales, are found to be dammed up at their lower end by loose unstratified materials, which must be regarded as a terminal moraine. Others of these lakes lie in true rock basins, or depressions excavated in the solid rock, and appear to exist at such places as would be the point of meeting of a great glacier and one of its tributaries. Here the mere increased weight of the ice may be supposed to augment the excavating power of the morainic stones in its floor. Several of the lakes of Cumberland are susceptible of explanation in this way.

Crater Lakes.—Finally, there are lakes which fill the craters of

old volcanoes, or occupy central depressions in the area which has been the core of a volcano. In the department of the Puy-de-Dôme there are 276 small lakes, formed more or less directly as a consequence of the accumulation of volcanic ashes or lava streams damming up valleys, or due to changes of level; but there are eighteen lakes still existing or filled up with sediment which occupy the craters of extinct volcanoes. In Central Italy several of these lakes of large size occupy the sites of old volcanoes. North of Rome one is more than 6 miles, and another 10 miles long. Others are seen in the Eifel.

Thus lakes are to be attributed chiefly to the action of lateral compression, which at once throws the earth's crust into folds, and heaves it out of the sea. They rise with tablelands, like the Great Salt Lake, which is 4000 feet above the sea; or Lake Titicaca, which occupies a depression in the tableland of Potosi, at a height of 13,000 feet in the Andes; and other lakes in Thibet rise even higher. When a lake is depressed beneath the sea-level, its position is always a consequence of evaporation; the depression is only some 80 feet in the case of the Caspian, but about 1300 feet in the case of the Dead Sea. The tendency of rain, and rivers, and glaciers is rather to carry material from a higher to a lower level than to excavate hollows, so that no large number of lakes of magnitude is likely to be attributable directly to erosive forces.

Lacustrine Strata.—Several of the British geological formations are inferred to have been deposited in lakes. The oldest of such formations is the Old Red Sandstone; for throughout the region over which it is spread there are no marine fossils, but plenty of land plants with the remains of fish, some of them allied to types which live at the present day in rivers and lakes; and at Kiltorcan, in the south of Ireland, a fossil shell has been found and referred to the freshwater genus Anodon. Hence the Old Red Sandstone is inferred to have been formed in great synclinal folds where the waters of the adjacent continent drained down and accumulated. In like manner the Coal Measures often speak incontestably to lacustrine conditions; and the fact that coal-beds succeed each other in vertical order, like the evidences of old land-surfaces in a delta, strongly enforces the inference that the intervening beds of shale and current-bedded sandstone, free as they usually are from typical marine fossils, were accumulated in waters which may sometimes have been brackish, but which were essentially lacustrine.

Passing onward in time to the Trias, with its beds of rock salt and gypsum, we have another formation which gives evidence of conditions which certainly included the evaporation and drying up of salt lakes; for the footprints, rainprints, and ripple-marks in the Cheshire Sandstones are more likely to belong to an ancient lake margin than to the sea. The freshwater and estuarine beds of the Lower Oolites of Yorkshire and Lincolnshire are quite as likely to have been lacustrine, though the lake certainly was not elevated on a tableland, as may have been the case with some of the salt lakes of the Trias. In the Purbeck formation we have evidence of lakes in which

calcareous deposits were formed because the sheets of fresh water rested chiefly upon limestones, but the limestones alternate with marls indicative of small streams which brought mud from time to time into the waters. Mr. Godwin-Austen, with the best evidence in support of his view, has taught us to regard the overlying Wealden formation, which is scarcely divided from the Purbeck stratigraphically, as another lacustrine deposit. But the physical geography of Europe had in the meantime somewhat changed, and the Wealden lakes accumulated chiefly, alternations of sandstones and clays with thin beds of freshwater limestone at intervals, and now and then an oyster shell, showing that the waters of the sea may sometimes have communicated with the great inland basin.

Tertiary deposits in the Woolwich and Reading series certainly make us acquainted with a lacustrine formation, which covered up with freshwater shells the leaves of trees and deciduous vegetation which grew on the lake banks. But this was a lake on much the same level as the sea, with the fresh water passing insensibly through brackish conditions to the sea, and giving evidence that sharks and other marine fish penetrated as close up to the freshwater lake as they do at the present day in some of the inlets on the western side of Scotland. After the elevation towards the close of the London Clay period, which is sufficiently evidenced by the multitude of fruits in which the clay abounds, upheaval culminated in the formation of the Lower Bagshot Sands, which appear to indicate lacustrine conditions; for not only are the sands filled with leaves of plants wherever there is a bed of clay in which these spoils of a luxuriant vegetation could be preserved, but the clay itself is, without exception, beautiful white pipe-clay, which could hardly have been the case had it been deposited from the waters of a great river necessarily charged with iron salts from the decay of the crystalline rocks, and with carbonic acid from the decay of vegetation such as is preserved. Finally, with the so-called freshwater strata of the Isle of Wight we enter on a period of time during which upheaval of the sea-bed took place, and lakes and lacustrine deposits became general in Western Europe, with occasional alternations of sea and land. The Headon beds, Osborne and Bembridge beds, and the Hempstead beds give us a scarcely broken sequence of old land-surfaces in the south of England, on which plants of varying kind succeeded each other, and ever-new types of mammals came down to the waters to die. The lakes on this ancient land, best evidenced by the limestones, persisted, sometimes changing their outlines and altering the character of the deposits formed in them, occasionally opening to the sea, and sometimes receiving new elements in their fauna.

Valleys.—A valley is a long depression or hollow on the surface of the earth, margined by ground more or less high. It may be broad and shallow, or narrow and deep. It may be surrounded by hills, or run through a country from sea to sea, entirely unassociated with mountains. On a large scale valleys are exemplified by the great depression which is filled with the Atlantic Ocean; on a small scale

we have the valley occupied by the English Channel or the Thames, and the still smaller valleys which branch about and form glens in the mountains of Scotland, or cwms in Wales. Almost every country offers examples of valleys through which the streams and rivers find their way to the sea, which differ from each other considerably in their scenery and origin. Since they are all formed by (1) the operation of the forces of compression which bend the rocks into folds, or by (2) the action of rain or ice or the sea which fashion and carve the irregularities of the earth's surface, or are due to (3) the alternation of the different kinds of rock which make the geological structure of the country, it is convenient to consider valleys according to the ways in which they have originated.

Valleys of Stratification.—In the middle districts of Britain, running from Yorkshire towards Dorsetshire, the several Secondary strata, which are chiefly alternations of limestones and clays, rest successively upon each other, tilted up at an angle, so that the several beds dip into the ground to the south-east. A clay is usually contained between two beds of limestone. The clay being formed of impalpable mud, has its surface particles loosened year by year under the influence of frost, and day by day by falling rain, which sweeps along the loosened particles, holding them in suspension, and delivers them to a river, which carries the waste material to the sea. Thus, in time, the clay becomes hollowed out into a valley more or less deep and broad, while the limestone, which is less easily broken up by the frost, and has few loose particles which can be carried away by moving water, and is only slowly dissolved by the carbonic acid which rain brings to the earth from the air, wastes less rapidly; and hence the limestone stands up as a terrace, margining the valley hollowed out in the clay below it. Such valleys are formed between the Chalk range of the North Downs and the parallel ridge of the Lower Greensand which extends from Guildford eastward by Leith Hill. The clay worn away is the Gault; the valley is the Holmedale. A similar valley lies between the range of the Lower Greensand and the parallel range of the Tunbridge Wells Sand in this Wealden area. It is formed by excavation in the Weald clay. A third valley is excavated parallel to the others between the Tunbridge Wells Sand and the Ashdown Sand, which forms the central boss or saddle of the Wealden anticlinal fold. This series of valleys, more or less distinctly marked, is repeated with a repetition of the strata southward, between the Ashdown Sands and the English Channel. So that in the little area of the Weald of Kent, Surrey, and Sussex there is a system of six parallel valleys which run eastward to the sea. The whole of the geological structure of the island offers repetitions of the same phenomena. The Vale of Pickering, in Yorkshire, drained by the river Rye, coming down from the Yorkshire moorlands, and by the Derwent, is hollowed in the Kimmeridge clay, between the terrace or escarpment of the Coral Rag and the Chalk. Similarly, in the south of England, in passing from Swindon to Bristol, valleys in the Kimmeridge Clay, Oxford Clay, and the Lias are crossed.

Some geological formations themselves form valleys or low ground, traversed throughout their extent by rivers. This is especially the case with the Triassic rocks. In North Wales, the Clwyd drains a valley of New Red Sandstone contained in a fold of older deposits. All the latter part of the course of the Dee and the Mersey is through the New Red Sandstone. A considerable part of the Severn traverses the same formation. The Trent almost wholly drains this formation, though its tributaries, the Dove and the Derwent, come down from escarpments in the Carboniferous rocks of Derbyshire. The Ouse flows through the Triassic rocks of the plain of York. In most of these cases the valley drained by the river is so little depressed that it can scarcely be regarded as a valley in the ordinary sense of the term.

Valleys in Tablelands.—River valleys, or valleys in plains, have long been distinguished from the valleys which occur in tablelands or elevated tracts. As regards their origin, they have nothing uncommon. When portions of the earth's crust are compressed, and a part rises upward, the adjacent part of the fold of necessity sinks downward, the elevated part being a saddle, the depressed part a trough. As the saddle rises in the sea, the waves cut its surface smooth, and as it rises higher, it often becomes fractured through its thickness by lateral compression. But at last, rising out of the sea as a plain, it begins to experience the wearing or solvent action of the rain, which, descending upon it, drains into the fissures, and makes them wider and deeper. As elevation progresses, the land rises higher, and the narrow valley is cut deeper and deeper. It happens that many tablelands are composed either of limestones or volcanic rocks, and just as a mountain brook, swallowed up by a fissure in the limestone, flows underground and excavates a channel for itself, which eventually becomes a cavern with steep sides, so the solvent power of the drainage-water, increased by carbonic acid liberated from decaying vegetation, has enabled brooks in mountain regions to cut deep and narrow gorges for themselves, which characterise limestone scenery. For these valleys the Spanish name cañon has been adopted. Similar valleys, however, are formed in some kinds of igneous rock. Thus, the broad sheets of lava which extend through California and the Rocky Mountain region are traversed by some of the most remarkable cañons in the world. Similar valleys of enormous depth extend through the tablelands of India. Though their origin is the same as the valleys in the limestones, there is a slight difference in the cause of their formation. The lava consists to a large extent of felspars and minerals which contain small quantities of lime, or soda, or potash. All these substances are capable of being taken into invisible solution in water which is charged with carbonic acid; and when the rock parts with any of them, its nature is changed. Previously it may have been hard enough to turn the edge of steel, and not easily affected by the beating of rain, or the pounding of stones which the torrent may have carried; but no sooner does the felspar part with one of its constituents than the rock becomes mud. And then the water sweeps the impalpable particles away, deepening the river channel, and emerges from the hills loaded with sediment.

Valleys in Low Plains.—But while the tableland was in process of being elevated and the mountain-peaks were being denuded from off it, the rolled and worn rock fragments thus formed were removed by tidal waters from the heights into the adjacent synclinal depression, as elevation went on. As this detritus increased in amount, the force of the waves carried it lower and lower and spread it out evenly; and when eventually this low plain rose from the sea, the waters draining down from the higher lands ploughed out a course over it, which is the simplest form of a river valley. Such valleys cut through the pampas-mud are typified by the channels of the La Plata, the Amazon, the Orinoco, and most of the rivers of South America. Something of the same sort of thing may be seen in the rivers of Siberia, which flow through a deposit of mud worn from off the plain of Thibet and the northern mountain chains of Asia, by a sea which has retired. In our own country something of the same kind, but on a small scale, is seen in the plain called the Carse of Stirling, which is a silt washed down from the hills of Stirling and Perth, through which the Forth passes to the sea.

But river valleys have generally been formed gradually during long periods of time, and have been excavated far more largely by the power of the sea than by the rivers themselves. When once a depression exists by which tidal waters make their way into the land, the rising and falling of the tide acts twice a day like a saw on the shores of the estuary and the river-banks, so as to waste the rocks and widen the channel. And when a land drained by rivers is slowly depressed in level, the sea is given an entrance further into the land, and so the tide widens the river valley at that point in the same way as it was widened at the river's original mouth. Thus by depression estuaries enter the land, and carve out channels which vary in breadth and depth, partly with the nature of the rocks, partly with the angle of their upheaval, and which are considerably influenced by the rate at which movements of the earth's surface go on. And at last the sea, covering broad tracts, rounds off the roughnesses of its work by tidal movement in waters of moderate depth, so as to take away the abrupt characters of the cliffs in the gorges thus excavated. Upheaval causes the land to emerge again in the same slow way as it was depressed, only with this difference, that much of the fine sediment denuded is carried away to the ocean, and the chief part of the detritus already accumulated will be swept out from the valley, so as to leave, when the waters retire, beds of gravel and of inundation mud upon what had formerly been an estuarine sea-bed. And when the emergence of the land is completed, a long and comparatively broad and shallow valley remains, with broad branching tributaries, at the bottom of which the river runs. Such a channel is the valley of the Thames, in the lower part of its course. Oftentimes the sediment swept out from a river valley by the sea, when the land was lower, remains at the mouth of the river as a delta, or has constituted the obstacle which caused a delta to be formed.

Synclinal Valleys.—There are two other kinds of valleys which,

unlike these valleys of erosion, owe their existence, directly or indirectly, to elevatory forces; hence they are called valleys of elevation. When the rocks are compressed so as to be thrown into parallel folds such as form the Jura Mountains and some other chains, then the small synclinal depressions between the mountains constitute valleys. In our own country the rocks have been too long exposed to denuding agencies, and too little contorted in times comparatively recent for examples of valleys of this kind to have remained unchanged. But many of the undulations of chalk scenery have been produced as a consequence of small undulations of the underlying rock. Valleys formed by contortion are nowhere more grandly exhibited than in the Western Territories of North America, where the rocks are thrown into multitudinous parallel elevations with intervening valleys.[1]

Anticlinal Valleys.—But when folds of this kind are formed beneath the sea, and rise slowly from out of it, the tops of the folds are broken away, because the rocks are stretched and cracked and planed down; and then atmospheric agencies complete the work of hollowing out a valley where a hill once had been. Not entirely, perhaps, in one geological age, but during immense periods of time, most of the upward folds in Wales and in many parts of the world have been excavated into deep valleys. The part of the country which had originally been a valley produced by elevation, comes to withstand denudation better, in consequence of the hardness imparted to its constituent rocks by compression, often thus forming the loftiest mountain peaks. Such synclinal folds are Snowdon and Moel Hebog. The valleys around such mountains, at their first compression, rose to immensely greater heights. It is like an illustration of the Scriptural teaching that "Every valley shall be exalted, and every hill made low." The valleys are innumerable which were formed in this way. Some of the broadest are the Bristol Channel, and probably both ends of the English Channel. In countries formed of old and contorted rocks, as many valleys have been produced by elevation, as have been excavated by erosion in countries formed of newer rocks.

Valleys have existed for all geological time, but it is not often that they have survived the changes of the earth's surface so that we can recognise their former extension. A few such examples, however, will come under our notice of ancient valleys excavated in the mountain limestone of the North of England, and afterwards filled up by the Trias, again to be partially cleared out by existing streams. And similarly among the Austrian Alps we shall find at Gosau and near Salzburg many valleys excavated in the Triassic rocks, in which Cretaceous strata have been deposited, in their turn to be laid bare by ravines cutting through them.

[1] Hayden, Reports U.S. Geog. and Geol. Survey of the Territories.

CHAPTER XI.

SUBAERIAL DENUDATION AND ITS RESULTS.

Wasting Effects of the Atmosphere.

The gradual wasting of the surface of the superficial parts of the earth is an important element in geological theory and history. The following examples of the varied results of atmospheric influences in modifying the surface of the works of nature and of man, form but a small fraction of current information on the subject.

The wasting effects of the atmosphere are those terrestrial processes by which materials are provided for rivers and the sea to transport and deposit in new situations. These processes are dependent on general humidity, variations of moisture, precipitation of rain, and variations of temperature.

It is not, however, always possible to distinguish accurately the effects of these several causes. Many natural agencies are often concerned in one operation, and the general result is the sum or the difference of their effects. The chemical action of the atmosphere is evident in buildings, and on the surface of certain rocks. The same process which slowly reconverts the mortar of walls into crystalline carbonate of lime frequently causes the pulverisation and bursting of the bricks, in consequence of the expansion of the small masses of lime which they contain.

The surface of bricks is often covered with a saline efflorescence, which is generally nitrate of lime, but sometimes chloride of sodium. The surface of the yellow limestone near Doncaster is sometimes covered with a nitrous efflorescence, and so is the calcareo-magnesian mortar made from it.

The Wind.—The agency of the wind as a denuding power is easily underestimated, though the amount of dust deposited from the atmosphere under ordinary circumstances demonstrates that much matter is carried by the air from a higher to a lower level. The modern invention of the sand-blast, by means of which glass, granite, and other substances are easily etched, illustrates experimentally the ways in which wind, blowing in prevalent directions, abrades rocks. And when we remark that the contours of the sandhills of Holland are exactly the contours of mountain chains, it is quite possible that the outlines of mountains are in the main to be attributed to the agency of

the wind. One of the most interesting examples of wind action is recorded from the harbour of Wellington, on Cook's Strait, in New Zealand, where, in a line of low sand hills, are sand-worn stones in every stage of rounding. The prevailing winds drive a cloud of siliceous particles from one set of dunes to the other until their angles are entirely removed, and they become rounded like the grains of sand in deserts. In this country, Æolian action is admirably seen in the pinnacles and crags on the top of Kinder Scout, a tableland of lower carboniferous rocks, on which pillars of sandstone are left, which often stand up in the shape of gigantic clubs or mushrooms.

Waste of Felspathic Rocks.—The exterior of most uncrystalline rocks and buildings is slowly eaten away by the moisture and carbonic acid of the air; but the influence of this destructive agent is most remarkable among the felspathic rocks, whether they were originally crystalline, like granite, or compact, like basalt. The felspathic

Fig. 46.—Millstone Grit, Yorkshire.

portion of the hypersthene rocks of Carrock Fell is so wasted that the crystals of hypersthene and magnetic iron project from the surface considerably. Some greenstone dykes are thus entirely decomposed to great depths from the surface, and whole masses of rotten granite wait only for an earthquake or aqueous action to be entirely reduced to fragments. Those who have seen the crumbled granite of Muncaster Fell in Cumberland, or Castle Abhol in Arran, surrounded by heaps of its disintegrated ingredients, must have been struck by the importance of this phenomenon in reasonings concerning the origin of many stratified rocks.

Both carbonic acid and oxygen act very decidedly upon the metallic, and particularly the ferruginous ingredients of rocks, and thus swell and burst them to pieces. Sometimes, however, this very cause seems to harden and bind the rock together, and to render it more durable. In general there is no certain test of the durability of

any stone but experience of exposure under definite circumstances. The Bath stone, apparently so permanent amongst its native hills, perishes in the salt air of Norfolk; and few calcareous freestones of any kind will long resist the carbonated and sulphurous atmosphere of London.

Preserving Power of the Soil.—It is worthy of remark that sculptured stones buried under ground are perfectly and even wonderfully preserved, while their fellows left exposed to the sky have almost crumbled to dust. In the course of excavations for the Yorkshire Museum at York, the statues which once stood between the arches of the nave of St. Mary's Abbey were discovered, some with blue, others with red drapery, one with gilded hair, all retaining the most delicate chisel marks. But at a few yards from them, at the west end of the church which they once adorned, the atmospheric influences have nearly obliterated a beautifully sculptured wreath of leaves round the doorway, so that antiquaries have doubted whether they were meant to represent the vine or the ivy.

Waste from Humidity.—Frequently, in looking at buildings composed of porous materials, like the Portland stone, or a grit freestone, we observe the parts which are overhung by a ledge, and thus kept in a state of continual shade and dampness, to be more rapidly consumed than the projections; but the parts which hasten soonest to decay are those near the ground where they are most affected by rain and moisture. The same rules are exemplified in many remarkable rocks, as, for instance, in the quartzose conglomerates of the old red sandstone of Monmouthshire and the millstone-grit of Brimham Crags in Yorkshire. The "Buckstone," near Monmouth, is a huge rock inversely conical, expanded above into a large area, but contracted below by continual waste to a narrow base of attachment. This process, a little further continued, might convert the Buckstone, as probably some of the stones of Brimham have been converted, into a "rocking stone."

From Changes of Heat and Moisture.—In northern zones of the earth the variations of heat and moisture are greatest on the south and west fronts of buildings, and in consequence those fronts to our cathedrals decay most rapidly. This is remarkably the case with the cathedral of York, built of magnesian limestone, which is in many places quite consumed on these fronts, but comparatively uninjured on the northern face.

The weathering of the surfaces of buildings by the fluctuations of heat and moisture is partly dependent on the structure and composition of the stone. The flagstone of Yorkshire is in many houses at Bradford gradually decayed grain by grain, so that the surfaces of the stone, continually renewed, and never permitting the growth of lichens, appear always neat and clean. The magnesian limestone of the same county, often traversed by veins of calcareous spar, presents frequently a cellular or honeycomb appearance, in consequence of the projection of these veins above the excavated limestone; but the coarse shelly beds of the Northamptonshire Oolites, and the irregularly laminated

millstone-grit, are decomposed in lines corresponding to the differences in the composition of the stone.

In these cases the stone appears to undergo gradual and continual waste, but sometimes the whole surface exfoliates. Basalt very frequently suffers this kind of waste, granite not rarely; and it has been sometimes supposed in these instances, that the atmospheric action merely discloses the incipient concretionary structure of the rocks.

From Frost.—Frost is likewise an important agent in reducing to smaller masses the materials of the earth. Some stone, if brought to the surface in winter full of its "quarry water," will break in pieces directly. Advantage is taken of this circumstance by the slate-workers of Stonesfield and Collyweston, who quarry their stone in the winter, taking care to shield it from the sun and the wind till the frost has acted upon it, with the aid of water, if necessary, which, by disclosing the natural fissility of the stone, permits the blocks to be cleft into thin, sound roofing-slate. Landslips in mountainous regions are, probably, much accelerated by the power of frosts. In ascending the Righi from Wäggis, on the Lake of Lucerne, we are much struck by the extraordinary length and continuity of the joints of the nägelflue. It is from these natural partings that the landslips fall, when repeated rains, snows, and frosts have worn or burst them open, and the water passing down them undermines the foundation of the cliff. Thus huge blocks, liberated from their attachments, roll down the steep descent, or half the summit of a mountain slides upon its argillaceous bed. Vast portions have thus slipped from the Righi towards the isthmus which divides the lakes of Zug and Lucerne, and others are preparing to follow.

Effects of Rain.—We come now to the effects of rain, and without dwelling on the general degradation of the softer surfaces of the earth caused by this agent, we shall proceed to show, that within the historic era hard and durable stones have been greatly furrowed by the rain; and that in more ancient periods, the precipitations from the air have carved channels of various kinds, and sometimes formed real though miniature valleys of great length and continuity.

On Monumental Stones, &c.—Many Druidical monuments in the north of England are constructed of coarse millstone-grit, a rock admirably suited for yielding those enormous blocks preferred by the ancient architects. Three huge Druidical stones, now standing near Boroughbridge, called the "Devil's Arrows," present us with an instructive lesson on the ultimate fate of all human erections exposed to the ravages of time.

The rain, beating for 2000 years upon these venerable pillars, has cleft their tops, and ploughed deep furrows down their sides. The grooves are deepest at the top, and become wider and less distinct towards the bottom; they cross indifferently the false-bedded layers of pebbles, and go directly downwards. One of the stones leans remarkably and threatens to fall, but an examination of the furrows shows the inclination to be of most ancient date, for they descend much farther down the pillar on the upper inclined face than on the under.

Similar effects of rain are visible to a greater extent on the bold crags, like Almias cliff and Brimham rocks, which crown the summits of so many hills of north-western Yorkshire, from some of which the Devil's Arrows were obtained.

In the valleys of Switzerland (Sarnen) blocks of limestone, which have fallen from the mountain sides, have been furrowed in the same way since their descent.

On Rocky Escarpments and Floors.—The carboniferous limestone of England has been little employed in building, except partially in old castles, where it seems durable. But those who know the magnificent ranges of scars which gird the hills of Derbyshire and Westmoreland, will acknowledge that few rocks seem more likely to endure the rage of the elements. Yet, on close inspection of these giant cliffs, the dry and bleached aspect, and smoothed angles, show plainly wasted surfaces. Those who have stood on Doward Hill, near Monmouth, to contemplate the rain-furrowed white limestone there, will not need another example. In the north of England analogous and more remarkable instances present themselves in the wide limestone base of Ingleborough, and in Hutton roof crags near Kirkby Lonsdale.

The vast limestone floor which supports the cone of Ingleborough is marked in all directions by natural fissures, and divided into compartments like a map.

If one of these compartments be examined in the western part of the mountain, its surface will be found scooped into little hollows which unite into a common channel, and terminate by indenting the edges and furrowing the sides of the fissure. They are, in truth, valleys in miniature, produced separately by the drainage of the several blocks.

The mere decomposing effect of the atmosphere produces on the edges of the stone a different effect, by wearing away the softer laminæ, but the smooth surface of the miniature valleys, their regular descent, winding course, and union into a common channel, show that they were fashioned by the repeated fall of rain.

This scar is nearly level, but in Hutton roof crags we have an opportunity of tracing the rain-channels over an immense surface of bare limestone rocks lying nearly level on the hill-top, but sloping rapidly down the sides to the east and south. On the level top of the hill the stones are variously worn in hollows and grooves irregularly united and running in different directions, according to little variations of the ground; but on the steep east and south slopes the channels are extended into long furrows, which, uniting at acute angles, enlarge, widen, and descend the hillside in lines following exactly the declination of the rocks, and stopped only by few and distant fissures, beyond which other systems of concurrent grooves begin.

Rain-Channels like Miniature Valleys.—It is impossible by drawings or descriptions to convey such an idea of the appearances of the Hutton roof crags, as to awaken in others the impressions which are fixed for ever in the mind of the observer. The astonishing resemblance which these little rain-channels present to the great system of

valleys which undulate the stratified rocks, seizes upon the imagination, and we re-examine all our notions of the origin of these great surface-undulations. The fissures in the limestone rocks which stop and swallow up the gathered streams, are analogous to those longitudinal valleys beneath the escarpments of the Oolites and the Chalk by which the rivers are turned at right angles to their earlier course, while the lower edge of the fissure corresponds to the escarpment itself, with its new system of denudations.

To see these rain and time-ploughed furrows winding in uncertain directions over the horizontal limestones on the hill-top, like a slow river in a level plain, but running a straight downward course on the slopes, like a stream descending from its parent mountains, is enough to impress on every beholder a secure conviction that the excavation of many valleys must be explained upon similar principles; that, as the feeble currents of descending rain, aided by long time, have been sufficient to plough their little courses, so the greater action of existing streams has been sufficient to work out their *actual channels*, though the excavation of the *broad valleys* in which they run, may have been accomplished by more violent and voluminous waters.

Effects of Inundations.—The slow but incessant action of rain beating perpetually on the hard and the soft surface of the earth, and removing grain by grain the materials loosened by the expansive agency of frost, and by moisture and chemical changes, may, in a long series of years, be more important in its effects than the violent water-spout, or the ravaging inundation of a bursting lake. Yet the effects of water-spouts are tremendous in countries composed of easily destructible or unequally indurated materials. A waterspout which fell above Kettlewell, in Yorkshire, committed terrible ravages in the narrow valley of the Wharfe, near Kettlewell and Starbottom. On the sides of the mountains in Cumberland, traces of these visitations seem utterly ineffaceable; and the memory of the sudden bursting of the Peat Bog, above Keighley, will long be preserved in the valley of the Aire. The floods which rushed simultaneously from the Cairn Gorum and other mountains, in August 1829, over 5000 square miles of Aberdeenshire and other counties, were of prodigious fury, removing hundreds of tons of large stones, whole acres of woodland, and almost hills of earth. The desolating effects of the bursting of the ice-dam which had formed the temporary Lake of Bagnes, are matters of history. The moving mass of water, mud, and monstrous rocks, which swept with violence down the valley of the Dranse, carried away forests, houses, bridges, cattle, and men. In six hours and a half it passed through an unequal and irregular course of forty-five miles, till lost in the Lake of Geneva.

Glaciers.—Glaciers are likewise to be enumerated among the powerful agents by which the higher lands are wasted, and materials provided for raising the lower. As the summer heat melts every year the lower portions of these long winding rivers of ice, and the heated ground thaws, the gathering water dissolves their foundation, and the whole mighty mass of snowy ice slides slowly down-

ward on its bed, where it ploughs up the stones, breaks up the rocks, and, adding their spoils to the accumulations from avalanches, finally throws down huge banks of rubbish at the foot of the glacier, which is thus surrounded by an immense mass of loose materials, called the terminal moraine, which is deposited as the ice melts.

Almost every valley in the Alps is more or less filled with this morainic matter, a mixture of angular stones and mud, which is often cut into by small streams. Every river bed in the dry season is a floor of large stones, more or less rounded, which travelled on the glacier

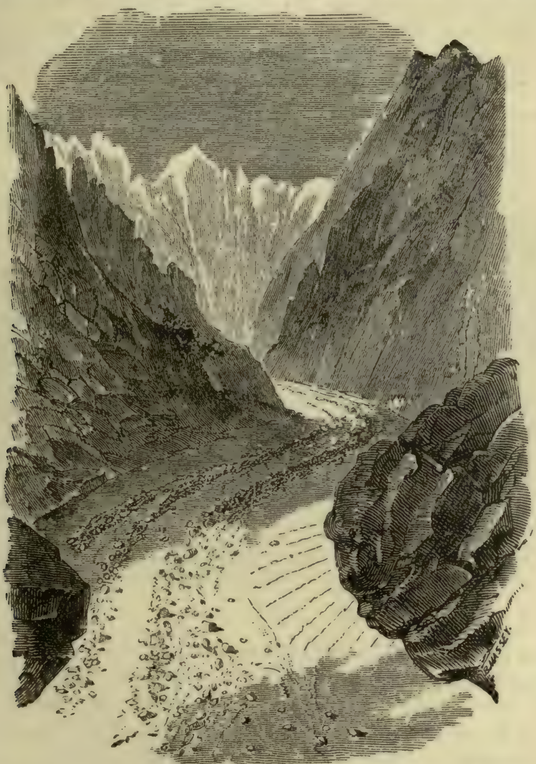


Fig. 47.—Track of a Glacier, Mer de Glace, showing median moraines.

before they were driven along by the mountain torrent and worn. The glacier wears its bed smooth, partly by the abrading action of rock fragments, which fall through cracks produced when the ice-stream squeezes through a defile, when they become unbedded in its floor, and rasp, groove, and scratch the subjacent rocks as the ice moves onward and grinds them into mud. Rocks thus worn show that succession of small rounded bosses which, from their resemblance to the backs of a flock of sheep, have been named *roches moutonnées*; they are well seen in Cwm Arthur, near Ffestiniog. The striated

surfaces are indubitable evidence of ancient glacial action. They abound in Switzerland and the north of Europe, and in our own country are excellently seen in North Wales about Snowdon, in the valleys of the Lake district, along the west coast of Scotland, and on both flanks of the Grampians. The morainic matter from the old British glaciers is spread along the country, and known to us as Boulder Clay. Where the mountain districts show marks of glacial action, they commonly exhibit vast blocks of stone perched in positions from which tidal waters would at once have swept them down. These masses, well seen in the Pass of Llanberis, are termed *blocs perchès*. They are portions of moraines which were carried by glaciers moving over the places where they occur, and as the ice melted away beneath them, they were deposited on the sides of the valley, on any ledge broad enough to afford them resting-ground.

Some small lakes are dammed up with terminal moraines. This

Fig. 48.—Conical Boulders (Arran)

is the case with Llyn Llydaw on Snowdon, and Llyn Idwal in Nant Francon, and many others in the lake district of Cumberland. Numerous mountain tarns which lie in true rock basins thoroughly glaciated, appear to have been excavated entirely by the erosive action of ancient glaciers.

Professor Ramsay has detected polished and striated boulders in the Permian Breccias of Enville in Worcestershire, the Abberley Hills, Clent and Lickey Hills, and other localities. In all cases the fragments are angular, and have been carried twenty-five to forty-five miles from the parent rock. These deposits testify to ancient glaciation.

Where a glacier runs into the sea, as in the Arctic Regions, and is buoyed up by the density of the water, the terminal fragment breaks off as an iceberg, loaded with the stones which have fallen upon it from the sides of the valley along which the ice travelled. As these icebergs are carried by currents into warmer water they melt, and

deposit upon the sea bed the stones they carried, or sometimes they are drifted on shore, and the boulders there accumulate. During the glacial period, when the British islands were at one time submerged, multitudes of such erratics became stranded on the higher ground as it emerged from the sea. But there are also evidences that icebergs played a part in the formation of many geological deposits: large blocks of granite have been found in the Chalk of Surrey, and blocks of coal in the Chalk of Kent, and angular fragments abound in the Cambridge Greensand, consisting of granite, mica schist, gneiss, basalt, and a variety of felspathic rocks, hard sandstones, conglomerates, slates, and limestones, occasionally with indications of carboniferous limestone fossils. Similar fragments are found in many of the Oolitic rocks, especially the Portland limestone, and large blocks of syenite have been recorded in the Coralline Crag.

Springs.—The precipitation of moisture on the surface of a country is determined chiefly by the configuration of the land and the direction of the prevalent winds; and hence high ground which rapidly radiates its heat, and thus condenses moisture out of the air, experiences more torrent-like denudation than the lower districts of our eastern and southern counties. But the character of the denudation depends not only on the quantity of rain and inclination of the surface over which it flows after reaching the earth, but also on the capacity of the rocks to absorb the water. Thus Mr. Mellard Reade, treating of the basin of the Thames, has estimated that of the rainfall of 27 inches 19 inches are absorbed by the porous rocks of the valley, and only about 8 inches drain directly off the land to the sea; while in regions of the more compact slate rocks of Cumberland and Wales, where the rainfall is far heavier, only about 10 inches are absorbed by the earth. But the water which is absorbed by the rocks passes through them to emerge again at a lower level when it is charged with various solids dissolved out of the porous beds. This underground flow of water gives rise to the phenomena of springs, in which most of our rivers take their rise. A spring may be defined as water flowing from the rocks, which was originally absorbed as rain at a higher level. Springs are classed into two kinds, commonly known as land springs and perennial springs; for thermal springs and the intermittent spouting springs termed geysers are varieties of perennial springs which make a transition towards volcanic phenomena.

Rain which falls on the surface of land where the subsoil is impervious, is partly absorbed by the superficial earth, gravel, or sand, and draining down the incline of the surface of the country, the water flows out from the surface bed as a small stream, which is termed a land spring. Such streams abound throughout the country, and determine the existence of many small sheets of water and the village ponds round which population has gathered. But not unfrequently these streams make their way to the sea, and, where the destruction of the cliffs is slow, produce, by their excavating power on the ground they run over, those miniature valleys which in the Isle of Wight are termed Chines, and are the Bunnys of Hampshire and Coombs of

other parts of the South of England. Where the cliffs waste more rapidly than the tiny streams can cut them away, waterfalls are shot over them into the sea.

The perennial springs draw their water from the porous beds among the regular geological formations; and all the tributaries of the Thames are derived from limestones or sandstones, usually at the point where they rest on clays. The fact that the water comes from limestone prepares us to find that it has dissolved from the rock, and holds in suspension in the river a large amount of solid matter. This solid matter, in the waters of the Thames and its tributaries, varies from 20 to 33 grains in the 100,000 grains of water, the average quantity being always upwards of 20 grains to the gallon. This invisible matter consists chiefly of carbonate of lime, but in the tributaries one-fifth of the amount, or more, may consist of sulphate of lime. In the lower part of the course of the river the amount of the solid matter is somewhat less, but every day about 1000 tons of carbonate of lime and 238 tons of sulphate of lime are said to be carried to the sea, with smaller quantities of carbonate of magnesia, chlorides of sodium and potassium, sulphates of soda and potash, some silica and a little iron, alumina and phosphates, making in all about 1500 tons delivered into the ocean daily by the Thames. Large as this amount is, the quantity removed is so small that, according to the estimate of Professor Prestwich, the surface denudation of the Thames basin at this rate by chemical means, would amount to less than one-tenth of an inch in a century, so that in the course of 13,200 years about one foot in thickness would be removed from the Chalk and Oolite districts.

Excavation of Caves.—When, however, the water is condensed into a narrow stream, as it often is in flowing under ground, its solvent action is particularly impressive. Charged with carbonic acid from the air, and further enriched with the same substance from decaying vegetation, the surface waters in the mountain-limestone country often disappear in fissures, called "swallow holes." The water here enlarges the fissure by dissolving the limestone, deepens the bed over which it flows, and gradually eats out the lofty chambers known as caverns. Many caverns have a branching ground-plan like a river with its tributaries, showing that when the infiltrated waters have been liberated in cracks within the rock, they have flowed on, excavating channels for themselves. It is only when the cavern admits of a certain amount of evaporation taking place that the erosive action begins to be counteracted by the deposit of the dissolved material in pendent masses descending from the roof of the chamber. These stalactites may grow, like columns, until the cavern is filled with them; for the drippings from the stalactites often form corresponding masses on the floor termed stalagmites, which rise up to meet the descending pillars. Many, however, of the most interesting caverns have been filled up with mechanical deposits before the stalagmitic covering was developed; and in such gravels or red cave-earth the remains of fossil mammals occur. The chief British caves

are in the Plymouth limestone, as at Brixham and Kent's Hole; in the Carboniferous limestone, as in the Mendip Hills, Derbyshire, and the district about Settle; and in the Coralline Oolite of Yorkshire at Kirkdale.

Streams which flow under ground, like the Mole in Surrey, which flows through the Chalk, traverse chambers which are still concealed.

Descending Streams and Rivers.

The wasting effects of the atmosphere are sensible in all regions, and therefore in every country some materials are available for the streams to transport. But the proportion of matter thus prepared in mountainous countries is so vastly greater than elsewhere, that in general, the less conspicuous effects of the same causes are overlooked in lower regions. The common notion respecting the action of alpine streams appears to be, that *these* are the principal agents of destruction upon the faces of the mountains, and that it is to them that the actual waste of the surface is to be attributed. But though these streams are indeed powerful agents of excavation, their principal influence is of quite another kind, and it is chiefly by the *disposition* of the materials brought into them by rains and avalanches that they effect such important changes.

Erosive or Excavating Action of Streams.—In considering the action of streams and rivers, we must distinguish between their powers of eroding or *excavating*, and of *transporting* solid matter.

The river works upon the channel and floodway, and its effects have relation to the *consolidation* of the matter traversed, and to the rapidity and volume of the moving water. About their sources, and for a long part of their early courses, streams continually deepen their channels, and wear away barriers of rock; but in their broad expansions near the sea, this power of excavation wholly ceases, as a general law, and is only seen in particular cases, as when great bends are cut off or banks undermined.

We have abundance of examples in all our mountain regions of the actual excavation of their channels by rivulets and rivers. In the district of Aldstone Moor, the south Tyne runs to the north from the side of Cross Fell, for some miles along a slope of shale, over the Tyne bottom limestone. In this shale, which is itself excavated into a broad valley, the river has evidently cut its own narrow yet sufficient channel; and no contrast can be more striking than that here afforded by the mighty valley of Tynedale, 1500 or 2000 feet below its bordering mountains, and the little channel holding the waters of the river Tyne. Every river works out its own channel in elevated regions, and in lower ground the soft clays and sands yield a passage to the feebler currents. In the level regions, along the rivers of Yorkshire, Lincolnshire, and Cambridgeshire, the channels have been many times changed, even by those sluggish streams; and still more in the deltas of the Rhine, the Nile, and the Mississippi; and among the Alps, fluctuation of the river courses is excessively irregular.

No doubt, then, can remain of the fact that some rivers and running waters excavate and alter their channels; though the changed course sometimes results from the deposition of sediment in the river-bed.

Lyell has given a remarkable case of *recent* excavation in a bed of modern lava of a channel from 50 to several hundred feet wide, and 40 to 50 feet deep, by the river Simeto, flowing from Etna. Scrope has also shown that similar phenomena have happened in the volcanic region of Auvergne. In these cases the action of the river has probably been excited by the flowing of a current of lava across its course, so as to dam up the waters, and give them something of the force of a cataract.

Waterfalls, &c.—The waterfalls and cataracts upon the line of a stream afford some curious points of study. It is especially in these cases that the increase of excavating power, derived by a river from the solid matter which it transports, is most evident.

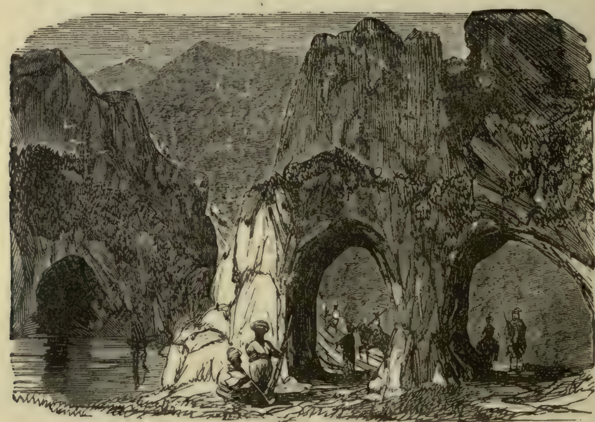


Fig. 49.—Balkan.

A cataract is formed upon the river Eden, in Westmoreland, near Kirkby Stephen, by some beds of calcareous red sandstone conglomerate. The pebbles which the river brings down, contribute with the whirlings of the water to excavate many deep perpendicular pits or potholes, similar on a small scale to swallow holes on the mountain limestone ranges, or those romantic cavities on the Caldew in Cumberland. Below many waterfalls in Wales and Scotland the same effect is produced. Near Christiana are deep pits of this kind, termed "Giants' Kettles," often from 30 to 40 or more feet deep. They have a spiral form like a corkscrew, are about four times as deep as wide, and contain the stones which were rotated to excavate them. They occur in groups near the sea, often at a height of 1200 feet; small kettles 18 inches deep have been excavated in eight or nine years by small streams.[1]

[1] Brögger and Reusch, Quart. Jour. Geol. Soc., vol. xxx. p. 750.

But the most characteristic effect of a cascade is that ceaseless undermining of its base and sides, and consequent rupture of the spout or edge of the fall, which causes the cascade by slow degrees to retire farther and farther up the mountain-side, and produces those deepening portals of impending rocks which so much augment the sublimity of a *waterforce.*

This effect may be excellently observed in the Carboniferous limestone district of the north of England, where so many streams leap from beds of limestone over perishing shales and sandstones, and rising in foam, sap and undermine the base of a large semicircular cliff, till at length the solid limestone crown gives way, and the insatiable river renews its destroying attacks. The same destroying power is seen in many of the Swiss waterfalls, particularly in the numerous falls of the Giessbach.

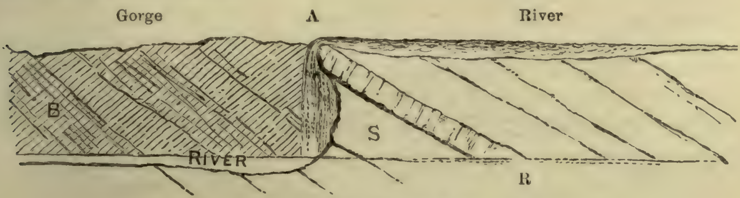


Fig. 50.—Diagram of a Gorge.

This diagram explains the mode of formation of a gorge (B) by the recession of a waterfall (A). The hard bed (R) dipping in the opposite direction to the course of the river, forms a ledge at A, over which the water falls, undermining it by excavating the soft shales (S); so that at length part of the ledge falls, and as the waterfall recedes the

Fig. 51.—Falls of Niagara.

gorge extends. If the hard beds are thin there is rarely a great fall. If the rocks dip in the same direction as the stream, rapids are often produced.

Lyell ingeniously applied the acknowledged fact of the recession

of the Falls of Niagara, which appear to have been pushed back several miles, at the rate of 40 or 50 yards in fifty years, to the possible discharge hereafter, through the St. Lawrence, of the waters of Lake Erie. Such a discharge, if it were brought about suddenly, would occasion a local *deluge;* but the lake is so rapidly filled up by sediment, that it is a question whether it will not become dry ground before the Falls of Niagara shall have been pushed back so far as to be capable of emptying it. Excavation at the rate of a yard a year would require twelve thousand years for the formation of the Niagara gorge, which is seven miles long. The Falls of St. Anthony, near the junction of the Minnesota with the Mississippi, have formed a gorge eight miles long to Fort Snelling. The falls have been receding since 1680 at an average rate of five feet a year, so that they may have required between eight and nine thousand years to excavate the valley, according to Prof. Winchell.[1] The Fall of the Rhine at Schaffhausen is a grand exhibition of the erosive power of water, particularly the wearing of the base of the island pinnacles of limestone, which now stand proudly in the midst of the currents, but will eventually be hurled down the thundering cataracts. The gorge of the Rhine, sixty miles

Fig. 52.—Gorge of the Rhine.

long from Bingen to Rolandseck, has been cut by an ancient waterfall, long since passed away, which has lowered the level of the Rhine and its tributaries, and drained lakes in its course, which are now small plains.[2]

Transporting Power of Streams.—In considering now *the transporting action of streams,* we may distinguish between such as flow through valleys of uniform declivity without lakes, and such as pass through broad receptacles of water before arriving at the sea, as is the case with several rivers of England, Wales, and Scotland, and streams which flow down from the Alps.

Rivers without Lakes.—A certain velocity of current is requisite for the transport of every kind of earthy matter; the finer the matter, the less the force required to move it along. Hence in the lower parts of rivers, where their course slackens, and they approach the sea, though they can no longer remove rocks and transport loads of sediment, their waters are muddy, and their channels and sides receive continual augmentation. Such a river as the Yorkshire Ouse is very instruc-

[1] Quart. Jour. Geol. Soc., vol. xxxiv. p. 886.
[2] Ramsay, Quart. Jour. Geol. Soc., vol. xxx. p. 81.

tive. As its branches descend from Shunnor Fell, Cam Fell, and Whernside, they transport daily and hourly from those elevated sites the materials accumulated by atmospheric agencies and mechanical attrition; the soil, the stones, the loosened rocks, grain by grain, and piece by piece, move onward with the current, and thus the whole mountain region, by a slow yet not imperceptible progress, is lowered in height, and its wasted spoils swept away for ever. But let us follow this process. Wherever the valley originally presented great inequalities, these are constantly diminished by the upfilling of the hollows, and at length the originally rugged chasm is changed by *additions* and *upfillings* into the smooth, evenly declining hollow, which, because of that smoothness and uniform declination, is supposed by many to be entirely a valley of denudation. In this process, the lateral action of rains and inundations from the sides of the valley is a very important auxiliary. Any one who contemplates the valleys of the Jura, near Schaffhausen, and sees them in many cases rugged on the sides, and evidently traced by nature in contortion, must be struck by the smooth, even, equally declining *plane* of their bottom, which cuts the rude precipices of the sides, and clearly indicates a subsequent powerful modification of the original roughness of the chasm. Still more abundant is the deposit of sediment as the stream glides into lower ground. There, above its narrow channel, rise the broad meadows, which, with every fresh inundation, receive a new coat of sediment, and above these swell the real boundaries of the valley, often consisting of water-worn materials, gravel and sand, left there by ancient floods of greater power, flowing at a higher level. As we approach the sea, when the tidal currents meet the freshes, the suspension of motion permits a great part of what sediment still remains to discolour the water, to drop on the bed of the river and its alluvial banks. Thus the streams become choked, their channels sinuous, their beds elevated, and the banks which confine the river, heightened both by nature and art, look like the ramparts and terraces of a lofty military road rather than the boundaries of a river giving passage to the drainage of the neighbouring country.

Taluses and Fans.—In the upper basin of the Indus, Mr. Drew [1] has described some remarkable deposits of sediment, due to the circumstance that the accumulation of the material is more rapid than its removal; though the like conditions may be observed on a smaller scale in our own Lake district and in all hilly countries. Wherever the rocks become disintegrated, they fall and accumulate taluses, such as may be seen on the south-eastern side of Wast Water, in Cumberland, extending for miles. The materials of a talus partly fallen and partly washed down by the rain generally lie at an angle of about 35°. Sometimes they expand downward in a fan shape, having its foot in a valley, and its apex in a steeper tributary ravine, giving the talus a vertical height, which is often 1000 or 2000 feet. Sometimes such a mass becomes infiltrated and cemented by calcareous

[1] Quart. Jour. Geol. Soc., vol. xxix. p. 441.

matter, so as to form a hard breccia. But often at the mouths of side ravines, where they open into a plain or wide valley, there are broad alluvial fans, well seen in Ladākh, in Kashmir. Such fans have a slope of about 5°, and an extent of about a mile, so that the apex rises some 500 feet above the surrounding plain. These depressed cones have been accumulated by the agency of streams bringing down loosened detritus from the higher parts of the mountains. Sometimes a number of fans unite together, as on the left bank of the Indus, opposite Leh, where they form a continuous deposit for thirty miles, which is fully two miles broad. The materials of the fan include more or less rounded blocks of granite, which may be as much as four feet in diameter, with sub-angular pieces of slate and shale, a few inches in diameter, mixed with gravel and sand. Occasionally these fans have been denuded by the Indus so as to form cliffs 50 to 100 feet high; and cases have occurred where a succession of fans has been formed and denuded one below the other, in the same locality.[1]

Fig. 53.—Fan at Tigar in Nubra, at Ladākh (after Drew).

The channels and banks at the mouths of rivers often extend outwards into a cape or headland, and contribute to extend the whole breadth of the bordering coast, so that by the waste of the uplands the low land is filled up, the river channels are raised, the coast is extended into the sea, and the sea filled with shoals and sandbanks. Thus the mouths of the Po, the Rhine, the Nile, the Euphrates, the Ganges, and the Mississippi, have formed for themselves those broad deltas which, within the historic era, have transformed ancient ports into inland towns, and extended fertile pastures into areas where the sea formerly washed.

[1] The fan-shaped masses are also commonly met with on the coasts of Norfolk and Yorkshire, where the finely-divided gravel, mud, and drift descend from the cliffs.

The substances transported by the stream, and deposited along its sides, are, of course, such as are furnished by the hills around its sources, and above its channel; and the almost incessant accumulations of earthy matter which thus take place, may be varied, according to the nature of the country, by interposed layers of vegetable remains. In tropical and warm regions, and in unenclosed countries, this is the case to a far greater extent than an acquaintance with European rivers would lead us to expect. The mighty forests of America, untouched by human industry, annually furnish to the great rivers which intersect them an immense spoil of trees, which being easily supported by the current, are carried towards the sea, and deposited at the river mouth, or drifted away on the waves.

Arrangement of Materials.—The arrangement of the materials brought down by streams is in general regulated by a tendency to the production of a level surface, and thus the original inequalities of a valley are continually lessened. In a high region like the Alps, the rough streams leave in the higher levels chiefly a collection of pebbles and sand in local confusion; but the general effect is a uniformly declining plane, through which the capricious stream finds for itself new channels, and thus continually shifts its deposits over the whole broad pebbly floor of the river valley. Such effects may be well seen on the line of the Arve, as it hurries down from the glaciers of Savoy. On the contrary, in the lower and more level expansions of a valley, where the gentler waters transport only fine sediment and vegetable substances, these materials are arranged in most exact parallelism over a large extent of plane surface, and by counting the laminæ of deposition, some notion may be formed of the period occupied in the process. On the borders of streams which are periodically swollen by rain, as in the tropical regions, or by the melting of snows, as in those which descend from high mountain countries, this mode of computation of the laminæ may even be trusted so far as to determine the number of years employed in producing a given depth of deposit; and in districts where the rivers swell irregularly at uncertain intervals, there might be deduced an *average rule* as to the rate of deposition. Nor would the accumulation during a short period of time, tried by this test, appear inconsiderable. In a single season, the rivers of Yorkshire, aided by the sea, deposit many inches of rich soil upon the level peat-moors which adjoin their estuary; and at Ferrybridge, at the point where the tide, formerly flowing up the river, neutralised the freshes of that river, many of the modern works of man, as oars of a boat, a coin of England, were found buried under the alluvial sediment, which contained petrified hazel branches and nuts, bones of deer, &c. The rivers of the Bedford Level have constantly silted up in historic times. The Great Ouse formerly (1292) joined the Nene and flowed out at Wisbeach, but as that outfall became silted up owing to the deposit of sediment by the stagnating waters, the whole drainage of the Level was diverted towards the outfall at King's Lynn. The inundations of the Nile raise the land of Egypt 4½ inches in a century.

From what has been said of the action of rivers, it is evident that their effects upon the physical features of a country are varied and interesting. The tendency of all descending streams of water is the same,—to equalise the surface of the earth, to remove its ridges and asperities, and smooth its depressions and fissures.

The degree in which they respectively perform this work depends, *first*, on the amount of atmospheric and local influences in wasting the surface of the higher ground, and bringing materials for the rivers to act upon. Hence the rapid waste of high Alpine tracts exposed to fluctuating heat and cold, to storms, avalanches, and glaciers. Hence the streams of sand and pebbles, which are carried from the gritstone hills of England; and, on the contrary, the almost unvaried purity of the springs which break from the Carboniferous limestone.

The *second* circumstance which determines the modifying power of the river is its own volume and velocity, and these are principally dependent on the physical geography of the region. The datum of the volume of water flowing in any valley is principally useful for comparison with the *observed effects;* the *kind of effect* produced being determined by the *velocity* of the current.

If we conceive that in its first fury a river may have power enough to sweep along even large blocks of stone, but that its velocity gradually diminishes, there will be a certain point where these large blocks will be left by the enfeebled current, pebbles will roll farther, coarse sand will travel beyond, and the finer sediment will be moved on till the languid waters permit their slow and equal deposition. This gradation of deposits is always observed in examining valleys of sufficient length and elevation. The deposits in the upper parts are tumultuous and confused, in the lower regions level and regular.

A *third* circumstance, of still more importance than the others, serves to regulate the action of the river. This is the *form and character* of the valley itself. However produced, there can be no question that the present aspect of almost every valley in the world is smoother and more equalised than it was formerly, since we see evidently, and take as a principle, that the characteristic effect of denuding agents in action is to reduce continually the inequality which remains. We may, therefore, easily, for each valley, restore in imagination its ancient condition, remove the sediment from its expanded meadows, and leave, instead of level or gently sloping plains that wind smoothly round the hills, and ascend far up toward the sources of the stream, deep chasms between cliffs rent asunder by convulsion, or eroded by tidal attrition, or the solvent chemical action of carbonated waters. That such has been the origin of many valleys is evident. That many of these may have been partly cleared out, and others wholly excavated by violent floods, sweeping over and denuding the land during its elevation from the sea, may be considered as proved. But we may content ourselves for the present with the *datum* that the fundamental features of valleys are not always the result of the excavating action of their

streams, but that valleys have been in part filled up by the accumulations brought by their own rivers; and that their present smoothness and uniformity is really the result of modifying powers of the sea, atmosphere, local influences, and the river combined, exerted through long time upon a ruder channel, left by more violent marine agents.

Rivers with Lakes.—Let us now see what peculiarities in the effects of rivers are occasioned by the circumstance of their traversing quiet lakes. Two things are here to be attended to. First, the lake causes, according to its extent, a more complete stagnation of the river movement, and consequent deposition of the sediment brought by the rivers, than is occasioned by the most level area of a river-valley; secondly, the materials dropped in the lake are regulated by somewhat different laws from those which direct their accumulation on an ordinary surface.

When a river charged with sediment expands into the waters of a lake, its motion, communicated to that large area in directions radiating from the place of entry, is checked and almost lost, and the sediment which it brought to the lake is gradually, and at last wholly, deposited; and the purified stream issues from the lower extremity without a taint of its stormy origin, *unless it be the colour*, due to mountain-peat, or some other substance held in chemical solution. Like the lake from which it escapes, or the ocean far from shore, it generally assumes the purest ethereal hue, its native tint of blue or green, but soon in its onward course again becomes turbid with sediment. Every lake in Switzerland exhibits these effects upon the rivers, which commonly enter turbid, and issue of a transparent green, though the waters of the Rhone are pre-eminently blue. These lakes are filling and contracting at their upper ends with the sediment which they gather from the rivers; and the process, though historically slow, is monumentally impressive, since we find large tracts of level meadows, cultivated, covered with trees, and supporting ancient and modern towns, where formerly flowed the deep waters of the lake. Thus the Roman town Portus Valesiæ, originally on the water's edge, is now nearly two miles inland, owing to the delta of the Rhone having encroached to that extent on the lake in the last 800 years, and behind Port Vallais the delta extends inland for five or six miles as an alluvial plain, which has displaced the waters of the lake.

All this *new land* was formed from the spoils and waste of the upper countries drained by the river, and is a measure of the effect of atmospheric and local influences in weathering the face of the hills, and of rivers in carrying away the materials thus prepared for them *since the earliest period when the streams began to flow* down the valley of the Rhone.

Arrangement of Materials in Lakes.—The second thing to be attended to in considering the effects of lakes on the line of rivers, is the arrangement of the materials which they receive. It is known to practical engineers that loose earth will remain at rest if it be placed at an angle not exceeding 45° with the horizon, and when loose, earthy

materials are poured from a height, they usually arrange themselves in a conical heap, whose sides make nearly this angle with the horizon. On the slopes of mountains liable to avalanches or rapid waste, the loose *débris* is usually found in a plane declining at about this angle. When streams falling over a ledge, transport with their waters a quantity of earthy matter, the conical heap so thrown down is very much more obtuse than when the materials fall dry, because their weight in water is less, so that the fall of the particles is not so direct, and the larger the proportion of water that comes down, and the more forcibly it descends, the flatter is the slope of the cone. This will easily be understood upon the principle that by partial suspension in water each particle is influenced by the tendency of that fluid to become level.

It is easy to understand from this that the form in which coarse sediment will be deposited by rivers entering a lake, must be in a very obtuse cone, radiating round the point of entrance. As the heap of sediment is advanced into the lake by continual additions, its outline remains circular, with a larger radius, and its section will be nearly level toward the land, but sloping more and more rapidly toward the interior of the lake. Were the particles to be arranged in obedience to the double forces of horizontal movement with the river, and of perpendicular descent from gravitation, the curve of the edge would be parabolic, and the surface left upon the sediment toward the land, nearly level.

But the earthy matter being unable to support itself at more than a certain angle of elevation, the lower part of the curve will become less steep, and be reduced to a straight line. Observations on the Swiss lakes assign to the sediment left therein an outline of this kind.

It is obvious that in these cases the sloping layers nearest the entrance of the stream are of older date than those farther advanced into the lake. It is an interesting subject of inquiry to learn whether, as is most probable, the particles of the sediment which differ in bulk and specific gravity, are arranged according to those qualities so as to constitute horizontal strata, of finer and coarser matter, &c. ; and whether, this being the case, the sloping lines of deposition, &c., are visible or obliterated in the section. In this manner the upper ends of lakes are filled almost to the surface with the deposits from the rivers ; and the dams of the lower ends of the lakes being worn away by the incessant action of the stream, these deposits become visible above the water, and constitute those smoothly declining, often moist surfaces, which usually confine within their indefinite border the shallow and weedy waters, destined in their turn to retreat from the desiccated land. While this process proceeds near the shore with the coarser particles, it is obvious that the finer sediment will be carried farther into the lake, and be spread more widely over its general bed.

These remarks apply only to deep lakes, whose waters rest tranquilly on their beds, and are only agitated at the surface. In shallow

lakes, which are agitated to the bottom, the materials must necessarily be distributed in planes very nearly horizontal, in consequence of the influence of fluctuations at the surface.

Lacustrine Limestones.—Before we dismiss the subject of lakes, it will be proper to take notice of another process tending also to fill them with new deposits. Many streams which enter lakes carry along, dissolved in their waters, a quantity of carbonate of lime, which may afterwards, by the loss of carbonic acid from the water, fall in calcareous sediment, and constitute beds of marl, or by the slow absorption by mollusca, be converted into shells. In the latter case, beds of Limnææ, Paludinæ, &c., are formed, and as the light argillaceous sediment entering such lakes is generally pretty equally diffused through the waters, the result is a bed of marly clay full of fresh-water shells. This process is daily going on, and in the course of a few years canals and river courses, as well as ditches and ponds, are choked by the abundant accumulation. In this manner, aided by occasional inundations bringing layers of vegetable matter, or detritus of the neighbouring country, many old lakes have become entirely filled up; and when the deposits are cut open for any purpose, they present layers of peat, clay, shell-marl, and sand, a faithful image, on a small scale, of those great fresh-water deposits which mark the force and extent of ancient currents on the surface of the earth.

Deltas.—The delivery of the sediment of rivers into quiet, tideless, land-locked seas is almost perfectly analogous to what happens in a large lake; but according to variation of circumstances, as the river flows into the open ocean, and contends with strong tides and sweeping currents, or discharges into a gulf, enters deep or shallow water, the disposition of its sediment is different. The most remarkable deltas at the mouths of rivers are formed round such as empty themselves into tideless seas, as the Mediterranean, Black Sea, Caspian, Baltic, &c., or into comparatively quiet bays of the ocean, as the Bay of Bengal, the Gulf of Mexico; and the least effects of this nature are accumulated on coasts which are subject to be raked by lateral currents of the sea. But it is probable that most deltas originate in the materials scoured off the surface of the land by estuarine waters, when the land last emerged from the ocean, which are swept out from the river valley and remain at its junction with the sea; so that the existence or absence of a delta may depend upon the rate at which the land is raised, and the angle of upheaval.

Most of the great rivers which enter the Mediterranean are daily increasing their deposits along the coasts, and spreading a quantity of sediment over the general bed of the sea. The Mediterranean has been proved by a line of soundings on the Skerki Shoal from the African to the Sicilian coast, varying unequally from 7 to 91 fathoms, to be divided into two basins. In the western portion, near Gibraltar, the bottom, consisting of sand and shells, has been reached at 5880 feet, and in the straits at 4200 feet, though between Capes Trafalgar and Spartel the depth is nowhere 1200 feet. Almost under

the shore at Nice the depth is 2000 feet; but in the Adriatic, where it receives the sediment of the Po and other rivers in the upper part, the greatest depth is 22 fathoms. Yet from the abrupt borders of the hill ground within the area of the sedimentary land, it is inferred that the Adriatic must formerly have been a deep gulf.

Nature of the Deposits in Gulfs, Estuaries, &c.—Farther from the influence of the rivers the depth increases considerably. Donati, on dredging the bottom of the shallow portion of the Adriatic, found it to consist partly of mud, and partly of calcareous rock, enclosing shells. The form of these sedimentary deposits must be what in common language is called horizontal, the substance of them is fine clay and calcareous matter with shells; and as the ratio of accumulation is nearly uniform, there will be little appearance of stratification, unless the calcareous deposits be formed at intervals. If by any effort of upheaval this bed of the Adriatic should hereafter be elevated and made dry land, as so many other extensive tracts along the borders of the Mediterranean have been, we should have an argillaceous deposit similar to the London clay, and perhaps identical with the subapennine marls, except for some difference in organic remains, and of such an area as would appear incredible to those who believe in the almost slumbering condition in modern times of the mechanical and chemical forces which modify our globe. The same conclusions might be derived from an examination of the mouths of the Rhone, Volga, Danube, Ganges, Euphrates, &c., which enter the sea under the same favourable circumstances, and transport enormous quantities of fine sediment into comparatively tranquil and now shallow waters. A river like the Mississippi, which hurries along an enormous volume of deep waters, and preserves its velocity to the edge of the sea, discharges a prodigious quantity of matter, which settles round its many mouths into a vast and growing delta. But the kind of matter here deposited and the mode of its arrangement will be different. Forests matted together by the growth of ages, with all their foundations, their alligators and other inhabitants, are swept down by this mighty stream, and either embedded for a time among its winding and variable channels, or hurried into the sea, and there agitated, and partially or completely separated into beds of earthy and of vegetable matter; and thus the Gulf of Mexico is now filling with deposits, which in no uncertain way simulate carboniferous strata. We are informed by Lyell, whose volumes are full of valuable information on all subjects connected with the modern operations of natural agencies, that a great part of the new deposit at the mouth of the Rhone consists of calcareous and arenaceo-calcareous rock, containing broken shells of existing species; and Admiral Smyth ascertained that over the broad, very gently inclined bed of this growing delta, marine shells were occasionally drifted by a south-west wind. In this way alternations of fresh-water and marine shells may be occasioned, in which the marine portions will predominate towards the sea and the fresh-water part be most decided toward the land.

The shorter and more rapid the course of a river, the larger and

coarser is the sediment which it may be able to transport. While the Po, slackening its velocity, deposits its gravel where it joins the Trebia, west of Piacenza, 130 miles from the sea; and the Ganges 180 miles above the commencement of its delta, and 400 miles above the present line of coast; the rough bed of the Yorkshire Tees is pebbly quite down to the sea; and the streams which descend by a short and furious course from the Maritime Alps, bear down pebbles into the Mediterranean.

From these instructive examples of pebbly, sandy, argillaceous, and calcareous strata, forming at the same era, in different basins of the sea, and even in different parts of the same basin, under similar conditions, enveloping deposits entirely marine, entirely freshwater, or partly marine and partly freshwater, we may turn with advantage to the contemplation of the older strata of conglomerate, sandstone, clay, marl, and limestone; and by carefully noting points of agreement and circumstances of difference, may frame satisfactory notions of the conditions under which they were respectively deposited. Especially we may be guided in our decision concerning the extent and connection or separation of the several basins of the ancient oceans, and the relative influence of ancient and modern rivers.

Bars at the Mouths of Rivers.—Rivers which discharge themselves into the sea, where tides and currents contend with the freshes, may, like the Rhine, be enabled for a certain time to deposit their sediment in a delta, and to increase this even to a vast degree, in consequence of entering the sea at a deep emargination of the coast, or amidst shallow sands which impede the action of the tide. But in such a case the accretion of land will gradually diminish, and at length the movements of the sea must balance the current of the river. In this case a line of sand-banks will be formed varying in position according to the alternate predominance of the contending forces, and the river entrance will have a bar. The Rhine, the Thames, and all the eastern rivers of England, are nearly in the same case. The sea, indeed, has again reclaimed from the Rhine, by most destructive floods, the large space of the Zuider Zee and the Bies-Bosch.

Thus also the seaward growth of the Nilotic delta, once so rapid, is greatly retarded or almost annihilated by a current of the Mediterranean; and the rivers of Western Africa, as well as the mighty Amazon, no longer extend themselves into the sea, but meet its currents in furious strife, drop the sand at their mouths, and resign their finer sediment to its disposal. The distance to which the ocean can waft this sediment on its surface along with the lighter fresh water is very great. General Sabine supposed himself to have crossed the discoloured waters of the Amazon 300 miles from its mouth, where it still retained its comparative lightness, and kept its place on the surface of the sea.

Thus may the sediments of distant countries be mixed or alternate, in deposits far from shore, and even in the deep sea. The distinctness of currents of water which flow down the same river channel, even with a rapid descent, has often been noticed. Thus

the Arve and the Rhone flow far without mixing, the Nahe takes one side of the Rhine, and even in the mining districts of England, the discoloured streams from the different valleys can often be distinguished along considerable lengths of a united river.

We shall not further extend our remarks on this subject than by mentioning a few instances of the actual extent of the deltas of great rivers. The whole area of the dry delta of the Po and the Adige, and other rivers which contribute to extend the same line of coast, must exceed 2000 square miles, and within the last 2000 years a space of 100 miles in length, and from 2 to 20 miles in breadth, has been added to the land. The area of the Nilotic delta is about 12,000 miles, and according to Girard the surface of Upper Egypt has been raised by the Nile sediment 6 feet 4 inches since the Christian era; the area of the Rhone delta is 1500 square miles; of the Niger delta is 25,000 square miles.[1] The delta of the Ganges, without reckoning that of the Burampootra, which has now become conterminous, is considerably more than double that of the Nile, and its head commences at a distance of 220 miles in a direct line from the sea. The base of this magnificent delta is 200 miles in length.[2]

The fen lands of Lincolnshire, Huntingdonshire, and Cambridgeshire occupy 1000 square miles, and the levels in connection with the Humber 300 or 400 square miles.

It has been attempted to deduce the age of existing continents from the rate of increase of the deltas of rivers within the historic era. Thus the Nile was supposed by Herodotus to have formed Lower Egypt; and he states that if diverted into the Red Sea, it would fill that gulf with its deposits in less than 20,000, or even 10,000 years. Since the time of Herodotus it is supposed that the increase on the Nilotic delta has been, upon an average, one mile and a quarter. The average annual growth of the delta of the Po, opposite Adria, which was once on the edge of the Adriatic and is now thirteen miles inland, was, from 1200 to 1600 A.D., 25 metres, and from 1600 to 1800, 70 metres; a very rapid increase of rate, probably connected with the increasing shallowness of the sea.

But all inferences from observations of this nature, and similar ones on the shallowing and conversion into land of the upper ends of lakes, can only lead to speculative results, without a knowledge of the original depth of the sea or lake at all points over which the river sediment has flowed, a datum very difficult to obtain; for it is not by the *area* of the delta, but by the *cubic content* of the sediment transported that the time occupied in the process is to be ascertained.

Rate of Sub-Ærial Denudation.—The average rate at which subærial denudation, however, goes on, is now determined with some approximation to accuracy. Professor Geikie finds that a large river carries away from its basin a mass of sediment which, if uniformly spread, would amount to $\frac{1}{6000}$ of a foot every year, so that taking the

[1] Dr. Fitton, "Geology of Hastings." [2] Lyell.

mean level of Europe at 600 feet, and supposing it everywhere worn down uniformly at this rate, little more than three and a half millions of years would be required to wear it level with the sea. But denudation is far more rapid in valleys and mountain regions; so that while $\frac{1}{12}$ of an inch may be removed in seventy-five years from plains and table-lands, an equal amount of denuded matter is carried away from valleys in eight years and a half, so that a valley 1000 feet deep might be excavated in 1,200,000 years.[1]

[1] Geikie, Geographical Evolution. Proc. Roy. Geog. Society, July 1879.

CHAPTER XII.

NATURE AND ORIGIN OF VOLCANIC ENERGY.

Continuity of Ancient and Modern Phenomena.—The resemblance between the stratified rocks now forming, and those which were deposited in ancient waters, has already become so manifest that, in most cases, we are compelled to use the same mineral names to characterise them, no matter what may have been the period at which they were formed. And when we turn our attention from the aqueous to the igneous rocks, exactly the same law will be found to govern their existence. The ancient forms of volcanic rocks consist of the same minerals as those which have been poured out from active or existing volcanoes. And although we are able to prove that the cores of ancient volcanoes, in which the rocks have cooled slowly under great pressure, can be so identified as to demonstrate their existence during all periods of past time, yet the variations in mineral composition, and even in chemical composition, of these granites and granitic rocks are small. We learn that the positions in which volcanoes formerly existed have from time to time been changed, and although volcanoes were recurrent in Britain during the Primary Period and the Tertiary Period, the Secondary Ages, except in the trias of East Devon, were as free from such disturbances as are British lands and waters at the present day. We therefore are led to inquire into the nature and origin of volcanic energy.

Nature of Volcanic Energy.—This, though usually manifested in an eruption, may exhibit itself in a multitude of other forms known to the practical geologist. We shall find the most important questions in connection with volcanoes to be, first, an explanation of the heat of the rocks; secondly, the source of the eruptive power which results in volcanic activity; and thirdly, we must account for the nature of the materials which are ejected from the volcanic throat, or consolidate beneath a mountain mass.

Internal Heat.—There are many ways of accounting for the heat of the rocks, but unfortunately they are all more or less hypothetical; and we find it necessary to adduce evidence if any view on this subject is to be accepted. A belief in the original igneous fusion of the earth was long the favourite doctrine. It is, however, quite possible that there may never have been any igneous fusion in the common acceptation of the term; and although the surface may have been

fused and incandescent, yet the earth may have been built up gradually by the infalling of meteoric matter. Either view gives us a high original temperature, which presumably has been reduced by radiation, so that the interior is now much hotter than the surface. It is well known that in mines, and deep wells, and borings, the temperature steadily augments, though the rate of increase varies with the locality; and the conducting power of the rocks is so variable that the increase of temperature beneath the surface is rarely regular. The most celebrated experiment, made at Sperenberg, near Berlin, reaching to a depth of 4172 feet, and passing entirely through rock salt, demonstrates that with increasing depth the distance which has to be passed through to gain an additional degree of temperature, augments. In the first 300 feet the increase was at the rate of 1° R. for 33 feet and 45 feet; at 400 feet and 900 feet the increase was only at the rate of about 1° R. for 500 feet; at 2500 feet it was 1° R. for 166 feet; and at upwards of 4000 feet 1° R. for 310 feet. In the first 1000 feet there was an increase of 11° R., in the second 1000 feet of 7° R., and in the next 2000 feet of 10° R., so that the rate at which the temperature augments steadily diminishes,[1] which may be only another way of saying that radiation is rapid in proportion to nearness to the earth's surface. In other localities the temperature at moderate depths increases 1° F. for 15 feet, and most of the temperatures fall between 30 feet to 60 or 70 feet for a degree.[2] In our own country, the average increase is 1° F. for 51½ feet. Hence we may conclude that an enormous amount of heat has been lost by the earth's surface cooling, that this loss of heat is still in progress, and that there is an immense amount of internal heat unexhausted. Whether temperature goes on augmenting to the centre of the earth, or whether it soon reaches a constant amount comparatively near to the surface, is a matter of small moment practically, if we bear the earth's rigidity in mind; for then, since the pressure of superincumbent rock increases beneath the surface, side by side with the augmentation of temperature, and since liquefaction of highly heated rock only takes place when the pressure is removed, it is probable that the temperature may never overcome the pressure so as to render the interior liquid. Since we can no longer assume a thin crust for the earth, it is impossible to believe this crust to be blistered by liquid rock boiling beneath it. And we as necessarily abandon the ideas that igneous rocks are protrusions of the original fluid substance of the earth, and that volcanoes are chimneys by which such molten rock rises to the earth's surface. Many eminent men of modern times, however, still accept the old idea of internal igneous fusion.

Hypothesis of Magmas.—M. Durocher propounded the hypothesis of there being beneath the surface rocks two magmas, from which all erupted rocks were derived. The outermost of these layers was supposed to correspond with the acidic rocks, and to have yielded

[1] See Fisher, "Physics of the Earth's Crust," p. 10.

[2] Mallet, "Report on the Neapolitian Earthquake," vol. ii. p. 310.

the granites, trachytes, and rhyolites; the deeper-seated layer, less perfectly combined with oxygen and silica, would correspond with the basic rocks, and was supposed to have yielded the syenites, diorites, basalts, and andesites.[1] Professor Judd[2] has gone a step farther, and assumed that beneath these layers are the unoxidised metals, which are occasionally brought to the surface in volcanic eruptions. Baron Richthofen, refining on this principle, recognised five of these successive magmas, which have yielded to the surface as many different kinds of volcanic rocks. All these views, however, imply original igneous fusion, increasing oxidation of the rocks towards the surface, increasing specific gravity on descending beneath the surface, and a thin crust through which the materials could reach the surface. Such views constitute an important school of geological thought, and they deserve careful consideration. But the whole bearing of field observation leads us to assign another interpretation to volcanic phenomena.

Hypothesis of Metamorphic Origin of Igneous Rocks.—For a long time only certain granites have been claimed as eruptive, while it has been conceded that in many cases, if not in most, they are metamorphosed slaty rocks, and have been elaborated in the positions in which they occur. We believe that the so-called eruptive granites will prove to be nothing but metamorphic granites, which have been displaced from the positions in which they were formed, by the forces which brought the rock into existence. If granitic rocks can thus originate independently of the supposed magmas, it is manifest that the liquefied forms of those materials, termed volcanic rocks, have also originated as products of metamorphism. Therefore we do not believe that the internal heat of the earth necessarily points to any order in the arrangement of igneous materials beneath the surface, or furnishes a logical explanation of the phenomena of volcanic energy.

Theoretical Influence of Radiated Heat on the Earth's Surface. The heat, however, which is radiated seems more competent to give rise to physical changes in the earth's envelopes, which connect the facts of metamorphism, of rock structure, and igneous phenomena, so as to explain their existence in a systematic way. For since nearly every known substance contracts in dimensions on cooling, it follows that in descending beneath the surface the rocks must be now undergoing a process of contraction. At the surface, where cooling is complete, contraction is complete. But if a warmer layer existed beneath this surface layer and inseparable from it, and cooled subsequently, it must contract, so as to draw the upper layer together laterally and throw it into folds. If we further suppose the cooling to extend deeper and deeper, then each successive addition of a new contracting layer below will increase the number and intensity of the folds and contortions of the surface rocks. And since the surface rocks are thus caused to occupy less horizontal space, they necessarily become variously crumpled, elevated, and depressed. This conception of plication of the earth's crust was first enunciated by Constant Prevost.

[1] See Haughton's "Geology:" Appendix. [2] "Volcanoes."

De la Bèche and many of the founders of geology either arrived independently at the same idea, or adopted Prevost's views. They thus eliminated the idea that upheavals were due to direct elevation from beneath; and affirmed that they result from lateral pressures, acting against each other in nearly horizontal directions, and transverse to the lines of elevation. The Rev. Osmond Fisher proved that the mechanical force thus originated was ample to account for the elevation of the highest mountains.[1] And this method of upheaval accounts for the diminished density of the earth which has sometimes been detected beneath great mountain-chains.

Observations which Illustrate the Theory.—Such changes in the earth's crust leave effects which are easily recognised; and we find indubitable evidences of changes of level now in progress in great masses of land. The depression of Greenland is well attested by the removal of settlements farther inland, and by the sinking down and submersion of islands off the coast.[2] A corresponding elevation of the north of Norway and Sweden, originally observed by Von Buch, was demonstrated by Lyell.[3] On our own coasts sunken forests, in many places, testify to depression; and the existence of raised sea-beaches proves recent upheaval. And as we go backward in time, the whole series of strata, with their alternations of deep-sea and shallow-sea deposits, with fresh-water beds and old-land surfaces, superimposed in the same region, afford incontestable evidence that the permutations of level of the earth's surface in past ages were precisely such as are now in progress in almost every sea; while the very existence of continental lands, chiefly composed of marine strata, demonstrates upheaval on a grand scale.

If, further, we examine the geological structure of almost any land, its strata are seen to be almost invariably thrown into undulations and grand upward and downward folds, such as have already been indicated in the structure of our own islands, and may be seen on a large scale in a geological map of Europe. And whenever we approach regions which have been greatly elevated, the intensity of the plication of the rocks always bears some relation to the height above the sea which is attained. Not rarely we find the oldest rocks the most disturbed, because they have been longest exposed to disturbing forces, but in many cases newer rocks are almost as much changed.

Mr. Robert Mallet's Theory of Volcanic Heat.—It is well known that all movement or pressure which meets with resistance becomes transformed into heat.[4] And Mr. Robert Mallet, F.R.S.,[5] developed the remarkable conception that the heat which produces volcanic energy is developed locally within the solid crust by transforming the mechanical work of compression into heat; while these compres-

[1] Trans. Camb. Phil. Soc., vol. xi. pt. 3.

[2] Arctic Papers of the Royal Geographical Society, Proc. Geol. Soc., vol. ii. p. 208. Quart. Jour. Geol. Soc., vol. xxvi. p. 690.

[3] Phil. Trans. Royal Soc. 1835. See also "Lyell's Principles of Geology."

[4] Tyndall, "Heat as a Mode of Motion."

[5] Mallet, "On Volcanic Energy," Phil. Trans. Royal Soc., vol. clxiii. p. 147.

sions are themselves produced along parallel axes, or over definite areas, by the more rapid contraction, from cooling, of hotter material of the earth's mass beneath the crumpled shell. For when the mass of a mountain, already forced up by lateral pressure, presses downward upon the resolved vertical force, so as to equal the resistance to crushing of the rocks on either side, then the further force of lateral pressures must be used up in crushing the rock between them to powder, or in developing such heat as shall render the mass plastic and so displace it. The contraction is necessarily greatest along lines or planes of weakness in the crust; and the heat developed in the rocks thus squeezed is necessarily greatest along those lines or planes or places where movement and pressure are greatest. If one bed of rock is less compressible than another, it will become more heated by compression. Thus quartz would become nearly three times as hot as clay, and communicate its heat to the adjacent beds. In such positions the temperature may rise locally to a red heat, or even to the point of fusing the rocks which are crushed and pressed together. Hence heat is produced beneath the places where it is exhibited in volcanic vents; and the heat produced locally is consumed locally in originating physical and chemical changes in the rock substance, and in the mechanical work of ejection.

This being the theory, the question arises, Is the compression competent to produce the results which are inferred? And upon this point Mr. Osmond Fisher has discussed some theoretical doubts in his "Physics of the Earth's Crust," to which reference may be made.

Evidence in support of Mr. Mallet's Views.—Mr. Mallet observes that under the ordinary conditions of experiment at the earth's surface, such a rock as granite or porphyry crushes under a pressure of 14 tons to the square inch. On the hypothesis of a contracting crust one mile thick, it is calculated that the lateral pressure per square foot would amount to 952,666 tons, or more than 472 times the force necessary to crush granite. The height of a column of rock which would be crushed by its own weight is about 4 miles; but the horizontal force is equal to a column of 2000 miles or one-half of the earth's radius; so that it is concluded that the resolved forces of gravitation will crush the solid crust if it is left partially unsupported, by the shrinking away of a contracting nucleus beneath. Mr. Mallet conducted a number of experiments to show that a considerable temperature was developed by crushing various rocks, though the heat thus obtained was less than the temperature under which crystalline rocks consolidate. The amount of heat lost from the earth every year by radiation, could be produced by crushing 987 cubic miles of rock; and Mr. Mallet estimated that, if used up in volcanic energy, it would be sufficient to produce all existing volcanic cones in less than eight years; so that only a minute fraction of the radiated heat of the earth can reappear in the form of volcanic activity.

Geological Evidence on the Nature of Volcanic Heat.—Whatever may be the value of Mr. Mallet's calculations, no matter whether the

force requisite to crush a rock will melt one-tenth or two-tenths, or any greater or less fraction of it, further contraction in deeper layers must develop additional heat in the crushed layers, and hence we may admit the sufficiency of the means to develop the heat which is necessary. But if these views are to be substantiated, they ought to receive elucidation from the structure of the rock in districts which exhibit effects of pressure; and in the ways in which folded rocks have been modified, should be found proofs that heat augments towards the centre of a region which has been uplifted by lateral pressure.

Where the rocks have been greatly compressed, as in Wales, the Lake district, or Scotland, the old clays are altered into slates. Their chemical composition is not changed, but they have lost their elasticity as much as clay which has been burned into brick. And Mr. Sorby has demonstrated, by sections of the rocks examined under the microscope, that this change is due to an incipient crystallisation by which a large part of the rock matter has become transformed into a mineral, arranged in minute plates which have the characters of mica or chlorite.[1] The immense compression and contortion which these rocks have undergone is well known, but nowhere perhaps better seen than in the section near Llanbabo in Anglesey.[2]

Whenever mountain-masses exist which show crystalline rocks entering into their structure, those rocks always occupy the central axis of upheaval and have the slates on their flanks. The outer part of the crystalline mass consists of schists, which show a foliated structure with the layers made up of crystals dovetailed and densely packed; and these rocks often pass by insensible gradations into slates on the outer limit, and into granitic rocks towards the central axis; while large bosses of indubitable granite are often exposed in the centre of the chain. Here is a sequence of changes, increasing in intensity, giving evidence, from more perfect crystalline texture, of augmenting temperature, as we approach the position in which the lateral pressures most perfectly antagonise each other, and become most intense. So that since the bulk of masses of granite and schists often bears some proportion to the evident elevation of the region in which they occur, as in the Pyrenees and Alps, though the present heights are often diminished by denudation—we may recognise in mountain structure and mineral condition, exactly such phenomena as ought theoretically to exist, if the heat which altered the rocks were produced locally by compressions. And under no other explanation can we account for the observed physical structure of mountain-chains.

Temperature and Pressure involved in Rock Construction.—There is no means of estimating the extreme slowness with which these changes have been brought about, except such as are suggested by the changes of level in land which have been observed to be now in progress; and although high temperatures may be necessary to approximate to similar conditions in our experiments, it is probable

[1] Sorby, Quart. Jour. Geol. Soc., vol. xxxvi. Address, p. 73.
[2] Ramsay, Mem. Geol. Surv., vol. iii. p. 246, fig. 100, new ed.

that, in the lengthened periods over which the natural operations extended, the heat involved may have been less than would at first have been expected; and it is more than probable that the phenomena are not to be explained by the action of heat alone. All experiments at the earth's surface are necessarily under a pressure which is infinitesimal in comparison with that of the superincumbent rock, which has since been denuded from a granitic district, sometimes for a thickness of miles, to say nothing of the force of pressure from lateral contraction which is superadded. And while the water within the rock at once escapes in a furnace experiment, the water is inevitably imprisoned in a metamorphosed rock, so that the conditions of the experiments are not the same. The presence of water appears to be necessary to the production of such crystalline forms for minerals as are met with in nature; for in blast-furnace slags, which are run out at a temperature of about 3700° F., only complex feathery skeletons of crystals are commonly formed, with those minute light and dark needles scattered in the glass, which have been named belonites and trichites. And when igneous rocks, such as basalt, are artificially melted, the augite crystallises in flat feathery plates, like those of furnace slags, which are rarely if ever seen in nature; and the felspar prisms end in complex fan-shaped brushes, so that the structure of the rock is changed by the conditions of liquefaction and consolidation.[1] Similarly when the Leicestershire syenite is fused and slowly cooled, the solid crystals are lost and replaced by feathery skeleton crystals of magnetite, and flat prisms of triclinic felspar ending in fan-shaped brushes. Dr. Sorby suggests that the difference is due to the presence and absence of water.[2] The quartz in schists was found by Sorby to abound in fluid cavities, the fluid being water which usually contains chlorides of potash or soda; which indicate in the schists of Cornwall a temperature of 392° F., and in the schists of the southern Highlands a temperature of 221° F. The quartz of granite also frequently abounds with fluid cavities, so numerous as not to be more than $\frac{1}{1000}$ of an inch apart, so that there may be a thousand millions or more in a cubic inch; and they constitute 5 per cent. of the volume of the quartz. Similar cavities also exist in the felspar and mica, though they are relatively rare. Crystals of sulphates and chlorides occur in these cavities. Gas cavities and stone cavities both occur. Dr. Sorby remarks, "The proof of the operation of water is quite as strong as that of heat; and, in fact, I must admit that, in the case of coarse-grained highly quartzose granites, there is so very little evidence of igneous fusion, and such overwhelming proof of the action of water, that it is impossible to draw a line between them and those veins where, in all probability, mica, felspar, and quartz have been deposited from solution in water, without there being any definite genuine igneous fusion, like that in the case of furnace slags or erupted lavas." While, from the fact that schorl melts readily at a bright red heat,

[1] Sorby, Brit. Association Report, 1880, p. 568.
[2] Sorby, Quart. Jour. Geol. Soc., vol. xiv.

and multitudes of hair-like crystals of schorl are enclosed in the quartz of Cornwall, it is inferred that the granite did not become finally solid at a temperature much higher than a dull red heat. The temperature inferred for an elvan dyke from the fluid cavities[1] is 608° F., which indicates a pressure of 18,100 feet; but most of the observations on Cornish elvans gave Dr. Sorby a pressure of 40,300 feet, while the quartz-porphyry dykes of the Highlands indicate, on similar evidence, a pressure of 69,000 feet. The granite of St. Austell in the same way indicates a temperature of 490° F., and a pressure of 32,400 feet, while near Penzance the pressure corresponds to 63,600 feet; the mean pressure indicated by Cornish granites is 50,000 feet. The mean pressure of the Aberdeen granite is about 76,000 feet, while the centre of the main mass of the granite of Aberdeen requires a pressure of 78,000 feet. Whence we learn that the inferred temperatures, under which these rocks were produced, are scarcely higher than would be reached at corresponding depths beneath the surface by the mere natural augmentation of the earth's heat, so that if anything like 50,000 or 70,000 feet of rock has been denuded to expose the granite, all difficulty as to the temperature vanishes; and the water, though greatly heated, was in most cases caught up by the crystals in a fluid state, more or less saturated with the alkalies which enter into the composition of the minerals forming the rock.

How Upheaval Facilitates the Outburst of a Volcano.—When a great upward fold of the earth's crust is in process of formation or further elevation beneath the sea, two things inevitably happen: first, the external surface of the rocks is stretched, and therefore fissured; and the greater the elevation, the deeper and more numerous these fissures must become. Down such cracks water would inevitably penetrate, and modify the condition of heated rocks with which it came in contact. Its presence in this form was probably unnecessary, as we may hereafter show, to the production of any crystalline rock; but such infiltrated water initiated changes which modified a rock, that might have become crystalline, into a fluid and eruptive form. And secondly, as the upheaved part of the earth's crust approached towards the surface of the ocean, it became cut down by denudation into a plain, so that an immense thickness of sediments was removed from above the central axis, where heat was already developed by a lateral compression; and when relieved of this superincumbent pressure, and the weight of the water by emerging from the sea, the pressure above the heated mass is so far reduced, that the expansive force of the steam and liquid rock overcomes resistance, and a volcanic eruption is possible. No small number of volcanoes exists in tablelands, or among mountains near to the sea. And if we find that granite, for instance, has become liquid and is poured out on the surface of the earth as a volcanic rock, and that the parent masses from which

[1] For a discussion of nature of this evidence, see Sorby on the Microscopical Structure of Crystals, &c., Q. J. G. S., vol. xiv. p. 453.

the streams flowed can be identified, another step is made in geological demonstration of the nature of volcanic activity.

Relation of Felsitic Bosses to Granitic Mountain Chains.—It is now well known that when granite is liquefied, and cooled so rapidly as to put on a micro-crystalline texture, it becomes a grey or reddish rock, which, to the eye, may be homogeneous or diversified with crystals of felspar. In this state it is known as felsite, felstone, petrosilex, or eurite; and when it assumes a foliated schistose form is known as hälleflinta. Professor Judd has described on the flanks of the Grampians[1] vast sheets of felsitic lavas of enormous thickness, mixed with ashes, pumice, scoriæ, volcanic bombs, and other evidences of ancient volcanoes, the parent materials of which can only be sought in the granite bosses of the Grampian chain. Similarly, in most of the larger islands of the Inner Hebrides, granite peaks occur, which are obviously the solidified cores of ancient and vast volcanoes, from which flowed the surrounding lava streams of felsite or rhyolite, and similar rock-substances. So that, without appealing to other instances, we believe these to sufficiently establish the conclusion that granites produced by metamorphism may be erupted, and pour out the rock-material in all the forms which characterise volcanic eruptions.

Linear Arrangement of Volcanoes.—If we now examine a map of the world, so as to observe the positions of existing volcanoes, they will be found running for the most part in chains or lines, which are regions of conspicuous upheaval, in some cases still undergoing perceptible elevation. Thus the chain of the Andes and Central America contains a multitude of well-known volcanoes, such as Corcobado, Aconcagua, Villarica, Osorno in Chili, followed by Viejo, Cotopaxi, Coseguina, Popocatepetl, and many more, succeeded in the United States by vast lava sheets in a region where volcanic activity is now all but extinct. On the opposite side of the Pacific, lines of volcanoes similarly extend through the Kurile islands southward by the Philippines; through Sumatra, Java, and adjacent regions; and wherever volcanoes exist they will be found to be in regions in which the force of upheaval is manifest. Or, to take the case of a single volcano, we have in Etna a vast mass where the base of the mountain consists of lava streams and ashes, alternating with marine sediments; proving that the mountain, even if it did not originate in a submarine eruption, has been greatly elevated during the progress of the eruptions, which have resulted in its present bulk. And if there are no corresponding evidences of changes of level of Vesuvius, the history of the Temple of Jupiter Serapis[2] attests that certain changes have taken place in the neighbourhood during the period of Vesuvian activity. And the elevation of the coast of Chili, recorded by Mr. Darwin, was contemporary with volcanic activity in the adjacent mountains. So that we have good ground for affirming that lateral pressure, similar to that

[1] Judd, "Secondary Rocks of Scotland," Quart. Jour. Geol. Soc., vol. xxx. p. 220.

[2] See Lyell, "Principles of Geology."

which elevates mountain chains, is one of the conditions of the linear form of volcanic activity.

Origin of the Eruptive Power of Volcanoes.—We next have to inquire into the source of the explosive and eruptive power of volcanoes, for the phenomena do not permit a belief that, the materials are merely extravasated through a crack by the uplifting force of lateral pressure. It has already been seen that volcanoes exist in positions where superincumbent pressure on the mass below must have been relieved by the formation of cracks penetrating from above, and the researches of Mr. Hopkins and Professor James Thomson taught us that, if a mass is greatly heated and kept in the solid state by pressure, it will become liquid as that pressure is removed. But it will not become eruptive; and the first sound explanation of the eruption was due to Mr. Poulett Scrope, who attributed it to the influence of water. This conclusion is almost inevitable, considering what enormous masses of steam are discharged from volcanic vents during eruptions, and how the vapour given off from Stromboli forms a constant cloud or mist above the island, while it may even give rise in Polar regions to showers of snow.[1] It is well known that in a closed vessel water may be made white hot without being converted into vapour; and if we suppose the water from the sea to penetrate down such fissures in the neighbourhood of volcanoes as have been suggested, then, heated beneath the surface by contact with rocks at a high temperature, it would escape by the path where the pressure was least, flashing into steam with explosive energy as the pressure disappeared.

Influence of Water on kind of Rock Ejected.—We have already seen how thoroughly some granitic rocks have their crystals saturated with water, which was included and caught up at a high temperature; and when this is borne in mind, it will be understood that heated rock has the power of dissolving vast quantities of water which produce many changes in its substance. The researches of Daubrée show that when common glass is raised to a temperature of 400 C., in the presence of its own volume of water, it swells up and changes into a mass of crystals of wollastonite; while the alkali is separated, and the excess of silica crystallises in the form of quartz. When the glass thus acted on contains oxide of iron, the wollastonite is replaced by diopside. Similarly, it was found that the volcanic glass obsidian, when thus treated, produced crystals of felspar, and was changed into a rock like trachyte.[2] And when kaolin was heated with a soluble alkaline silicate and cooled, the mass was converted into crystalline felspar, and quartz. It is thus seen that water plays a very important part in the formation of volcanic minerals, as well as in the actual eruption.

Mr. Scrope inferred that the presence of water would render the particles of mineral matter easily movable upon each other, and that the rise of lava in a volcanic vent is occasioned by the expansion of

[1] Scrope's "Volcanoes," 2d edition, 1862, p. 38.
[2] Sterry Hunt, "Chemical and Geological Essays," p. 6.

the highly compressed steam which it contains; comparing the ebullition to the expansion which takes place when the cork of a soda-water bottle is drawn.

Depths at which Volcanoes Originate.—It is almost impossible to estimate the depth at which volcanic phenomena originate. Mr. Mallet's investigations assigned to earthquakes a depth of from three to ten miles, and although they occasionally reach a depth of 30 miles, according to the late Dr. Oldham, they are obviously phenomena of the superficial portion of the earth's crust. Although these disturbances are probably different in kind from volcanic phenomena, yet they must often be consequences of the disruption in which a volcano originates; and so far may give some idea of the depth to which water must penetrate before it reappears in a volcanic outburst. There is another form of evidence adduced by Mr. Sorby, in the size of the fluid cavities relatively to the fluid in minerals ejected in blocks of volcanic rock from Vesuvius. Some of these in the mineral nepheline indicate a temperature of 706° F., equal to a pressure of 3222 feet.

Why Eruptions are Intermittent.—It is a well-known fact that, in the majority of volcanic regions, eruptions are intermittent. This circumstance is well exemplified in the history of Vesuvius; for although presenting the form of a volcano, there was no record of an eruption prior to the year 79; and it was not till the year 203 that a second eruption is described, while the third took place in the year 472; and frequently intervals of several hundred years have occurred between the eruptions, though for the last two hundred years the intervals of tranquillity have rarely lasted longer than five years. Almost the only exception to this paroxysmal condition among volcanoes is furnished by Stromboli, which is unceasingly active, and more like a solfatara than a volcano. The reason for this intermission in the outbursts is not far to seek according to the principles which we have so far developed; for with the progress of an eruption the amount of water which is given off in the form of steam diminishes; and if the water slowly infiltrates down to great depths, the supply must be more readily exhausted through the wide vent of an eruption than renewed through minute fissures; and therefore, as the explosive force fails, the eruption fails But we further conceive that the evacuation from beneath the surface of the vast masses of matter which are poured out in volcanic outbursts, takes place more rapidly than the contraction of the rocks can progress, in consequence of the radiation of heat; therefore, there comes to be a failure of the lateral pressure, which generates the heat that is the primary cause of an eruption. And until a sufficient interval of time has elapsed for the renewal of these elements of volcanic energy, the eruption must be intermitted. But the intermission may to some extent be due to the strength of the cone, and the security with which its throat and various apertures have been plugged by rocky materials; but, if the force necessary to burst a way to the surface is small, then feeble eruptions may take place frequently, or even in continuity.

Extinct Volcanoes.—Many examples exist of volcanoes which have so long ceased to be active that they are regarded as extinct, and we must attribute the failure of their eruptive power in most cases either to changed conditions in the relations of land and water, which have deprived the countries where they occur of the requisite water supply for the generation of steam, or to the exhaustion of rock-material beneath the surface, which was capable of producing ashes and lava, or else, as is probably frequently the case, to changes in the direction of the grand contractions beneath the surface, by which the subterranean energy became transferred from a region where it was formerly manifested, to a new locality—changes which have taken place in all past periods of geological time, with the result of altering the distribution of sediments, and of life, as well as of volcanoes.

Relation of Volcanoes to Stratified Rocks.—Finally, the materials which volcanoes bring to the surface remain to be examined It is well known that though these present in the rock-substance every variety in texture, yet at different times, and in different regions. volcanoes pour out ashes and lava which differ materially in their mineral and chemical composition. As we have already observed. rocks which are poor in silica, like basalt and the leucite basalt of Vesuvius, form a group which has been termed basic, while the trachytes and rhyolites, which are rich in silica, form another series of volcanic rocks. Why these two groups, which were recognised by most of the early masters in geology, should exist and alternate, is a problem that can only be estimated by recognising that, the alternation has existed for all geological time. But we might fail altogether to elucidate this problem unless we observe that, some of the ancient volcanic cones in the Eifel, as remarked by Professor Judd, are largely made up of fragments of slate, which have been ejected from the vents by explosive forces. And it is well known that the surface of Vesuvius is covered with fragments of limestone, ejected from the throat of the volcano; and many of these blocks are so little altered that Professor Guiscardi has been able to recognise several hundred species of shells in these masses. We thus discover that, deep beneath many volcanoes, stratified rocks exist; and as we are compelled to believe that the plutonic rocks were metamorphosed out of such stratified materials, so we find no anomaly in the basis of a volcano being formed by the liquefication of similar strata, nor indeed is there any other probable explanation available for the diversity of lavas ejected. All the phenomena which are connected with the existence of volcanoes are hence related to each other in a sequence, which owes its existence primarily to the cooling of the earth's crust.

CHAPTER XIII.

THE MANIFESTATIONS OF VOLCANIC ACTION.

Historic Records.—The circumstances connected with volcanic eruptions are either mutually dependent, or naturally connected with each other. For, whether exhibited as outbursts of ashes, lava-flows, mud volcanoes, sulphur springs, geysers or hot springs, they are attributable to the action of heat upon water, beneath the surface of the earth; and the phenomena only differ with the different conditions under which the heat is developed, and the water gains access to the subterranean regions. We obtain the clearest conception of the modes of action of these agents, in their geological relations, by examining the history of the origin of new volcanoes. Some of these are marine, others are on land; and although these new outbursts appear to differ fundamentally from older volcanoes, in having been in eruption but once, it may well be that there is nothing exceptional in such a circumstance, since the most celebrated volcanoes have had long intervals of repose.

Graham Island.—On the shallow sea-bed of the Mediterranean, between Tunis and Sicily, at about sixty miles from Sciacca, and thirty miles from the island of Pantellaria, an eruption took place in 1831 which built up a submarine cone. This volcano, when largest, rose above the sea to a height of 200 feet, and attained a circumference of three miles. Formed, however, of loose materials, it rapidly wasted away under marine attrition, and its position is now only marked by a shoal. Such an eruption is peculiarly instructive, as demonstrating how unsubstantial is the fabric of which a volcanic cone consists, and as indicating the nature of the evidence for the former existence of a submarine volcano, which the geologist might expect to find when the consolidated core left at its base by denudation was enveloped by sediments.

Jorullo.—A scarcely less instructive history records the eruption which formed Jorullo in Mexico in 1759. Prior to that date, the farm of Jorullo was laid out in sugar-cane and indigo. It was situate more than 100 miles from the coast, about 2500 feet above the sea, and far away from any active volcano. This farm was bordered by two streams, named Cuitimba and San Pedro. The first indication of disturbance consisted in hollow subterranean sounds, accompanied by constant earthquakes, lasting for about two months; when, after a

short interval, on the 29th of September, the ground opened, and thick clouds of ashes and rock fragments burst into the air, with the appearance of flames along the fissures. So sudden was the outburst, that it became known to the farm-servants by ashes falling on their hats. The two rivers were swallowed up in the open chasms, and in a short time the eruption built up six volcanic cones which extend in a line. One of these, called Jorullo, rises to a height of 1600 feet above the plain, which was formed around the volcano from ashes and basalt, poured out to a depth of 500 feet, in a deposit which thins away so as to give a convex appearance over an area of about four square miles.

When Baron Humboldt, twenty years later, crossed this district, termed the Malpais, the heat in a fissure in lava was still sufficient to light his cigar; and he records that the rivers, which had disappeared on the day of the eruption, flowed out again a mile and a quarter farther west as hot springs, which then had a temperature of 126° F.

The whole surrounding plain was covered with thousands of small cones, 6 to 9 feet high, which gave off vapour rising to a height of 20 to 30 feet; and the ground gave out the peculiar resonant sound when struck which, is known to the Italians as the rimbombo. Since its formation Jorullo has shown no signs of activity, and in this respect is comparable to the Monte Nuovo, produced in the Phlegræan Fields in September 1538.

Structure of a Volcano.—Although it is not possible to examine far into the structure of active volcanoes, yet it is not difficult to conceive of the steps by which a cone is built up. Although dust may sometimes be ejected, according to Mr. Whymper, to a height of 20,000 feet, and carried, as we have already seen, to great distances, it as a rule is simply shot into the air, and falls down again, so that most of the particles descend round the spot from which they were thrown up; and the thickness of the deposit becomes less and less farther out from the eruptive throat. But although the materials of the flanks of the cone may thus come to be arranged in layers, something like coarse gravel, which are inclined outward, some of the material falls within the sloping throat, so that the layers dip towards its centre; and wherever a volcano has been naturally dissected by denuding agencies, as in the Auvergne and Eifel, this condition is well seen. The whole mass then shows an irregular stratified appearance, crossed and bound together transversely by the walls of lava, termed dykes, which have been injected into fissures, opening downward.

Sequence of Events in an Eruption.—The succession of events which constitutes a volcanic eruption is variable in different volcanoes, and at different times in the same volcano. Professor Dana tells us that in 1789 Kilauea, in the Sandwich Islands, poured out an enormous quantity of light pumice-like scoriæ and sand which darkened the air. Whereas the well-known outbursts of that volcano have consisted of fluid lavas, which have sometimes run down to the sea. Similarly, in the grand eruption of Vesuvius in the year 79,

no lava appears to have been produced, but enormous quantities of dust and ashes, which sometimes ran down the mountain in torrents of mud; while at other times Vesuvius has ejected ashes and lava.

The differences in these conditions are attributable to the supply of water. Professor Dana has inferred from the fact that borings on a sea-shore will always yield fresh water, that the water is more likely to be fresh than salt; and that the rains and melting snows, absorbed by the cavernous rock of which a volcano consists, may contribute materially to supplying the explosive force to the fires below. But, on the other hand, many of the springs in Italy contain a perceptible amount of salt; and since the volcanic fires rise from a depth far below the sea level, the pressure of the sea must exert itself in forcing water into the rocks. It may be doubtful, perhaps, how far the substances dissolved in sea-water contribute to volcanic phenomena, but we may remember that though the salts consist chiefly of chloride of sodium and magnesia, lime and potash, chiefly in the form of chlorides and sulphates, Dr. Forschammer detected minute quantities of a large number of elements, such as from time to time are met with in volcanic and other igneous rocks.

Steam.—If we suppose water ready to take the form of steam, to accumulate beneath the surface until the pressure becomes so great as to burst a way through the rocks, as they become flexured, fractured, and heated, and then to expand, it becomes intelligible that the steam will be discharged with such force as to rise to a great height in the air, before it is chilled so as to condense in clouds. The force of the steam accounts for the abrasion and trituration of rock-fragments from the side of the eruptive throat, which, as we have already seen, are sometimes brought to the surface. But after a time, especially in the volcanoes of the south of Italy, dust is thrown up with the steam. This dust is not merely grated down from the rocks at the sides of the fissure, but is at first of such indescribable fineness as to remain long suspended in the air. The heated rock beneath the surface is in fact so charged with water that, when it comes towards the surface, the water expands into steam, blowing out the films like soap bubbles, so that they cool and contract; and becoming broken, fall into the finest powder.

Eruptions of Ashes.—An excellent example of a dust eruption took place in the volcano of Coseguina in 1835. This cone is situate on the Bay of Fonseca, in Nicaragua, and is about 500 feet above the sea. Slight noises were heard, and smoke was seen on the 19th of January, and on the 20th a cloud was thrown up, which, seen from San Antonio, 48 miles south, looked like an immense plume of feathers; at first white, then grey, yellow, and finally crimson, and expanding rapidly in every direction; columns of fire shot up, and there were severe earthquakes. On the 22d the sun shone brightly, but in the direction of the cloud there was intense darkness. A fine white ash began to fall, and in half an hour the day, at San Antonio, became darker than the darkest night, so that people could touch without seeing each other; the cattle came in from the surrounding country, and the

fowls went to roost. At twelve o'clock on the following day, objects could be distinguished at a distance of twelve yards, but the light was thus obscured for two days longer. All the time a fine impalpable white dust fell, which covered the ground at San Antonio to a depth of 2½ inches, in three layers; the lowest dark, the next greyish, and the upper whitish. The light continued partly obscured for twelve days more—the darkness, of course, being due to the quantity of ash in the air. At Nacaome, 24 miles north, the ashes which fell four or five inches deep, had a fetid, sulphurous smell. On the 23d, the sky was light enough to show that a fresh eruption had taken place; and in three hours darkness returned as on the 20th. When the atmosphere became clearer next day, the houses were covered with ashes to a depth of eight inches. Twenty-four miles south of the crater, ashes covered the ground to a depth of more than 10 feet, destroying pine woods. The thickness of the ash deposit varied somewhat with the wind, but so fine was the dust that it was carried as far as Chiapa, 1200 miles to the north, while at St. Ann's, in Jamaica, 1700 miles N.E., the sun was obscured on the 24th and 25th of January, and showers of fine ashes fell over the whole island, so that they must have travelled at the rate of 170 miles a day.

The surface of the Pacific, 1100 miles S.E. of the volcano, was covered with ashes, and a ship ran through 40 miles of floating pumice. This eruption of Coseguina is especially interesting, because Aconcagua and Corcovado were active at the same time.

The eruption of Vesuvius in 472 is said to have covered all Europe with ashes which even fell in Constantinople; and on various occasions the ashes from the volcanoes of Iceland have covered the North Sea, and fallen in Scandinavia. Perhaps the most remarkable evidence, however, of the extreme fineness of the dust is furnished by those great deposits of red clay which characterise the central regions of the Atlantic and Pacific Oceans.

Red Clay in the Deep Sea.—Mr. Murray reports that the deep-sea clays and deposits at a greater depth than 2000 fathoms appear to be always due to the decomposition of ashes and volcanic materials. The red clays owe their colour to oxide of iron; the chocolate-coloured clays are tinged with oxide of manganese, a mineral that abounds in sea-bed regions covered with augitic materials. Most of these clays contain little carbonate of lime, and those of the North-West Pacific abound in siliceous organisms. Amorphous matter rarely makes up one-half of the clay, and the remainder consists of quartz, mica, pumice, peroxide of manganese, and other minerals. Peroxide of manganese is always present, and sometimes makes up one-half the deposit, but quartz and mica are only characteristic of the North Atlantic. Occasionally copper, cobalt, and nickel are found in the clays. Pumice and scoriæ are universally distributed, some of the bottoms at 2900 fathoms being largely made up of finely-divided pumice. Pumice was dredged by the *Challenger* in at least 80 stations in masses from the size of a pea to that of a cannon-ball, and is most abundant in the neighbour-

hood of volcanoes, and in the deep-sea clays far from land. It is more frequently found in the Pacific than in the Atlantic. The pumice is sometimes coated with peroxide of manganese, and may be white, grey, green, or black, as it is felspathic or augitic. It contains crystals of sanidine, augite, hornblende, olivine, quartz, leucite, magnetite, and titaniferous iron. Magnetic iron is found in all the masses. Although a good deal of the pumice may be derived from volcanoes which girdle the Pacific, yet no inconsiderable quantity is derived from land, being washed down from the mountains by the rain, and floated to sea by the rivers. Thus, in Iceland, a ferry is said to have been blocked for days by floating pumice. Quantities of pumice float on the Amazon, brought from the region of its head waters. The river Chile, in Peru, has cut gorges 500 feet deep through pumice, and carries the fragments to sea.

Mud Streams.—Mud streams frequently descend from those volcanoes which throw out fine ashes. This may be due to different causes. The vast quantity of steam thrown out becomes condensed into rain, and this falling on the mountain, washes down the ashes in torrents of hot mud. Such streams are well known to have descended from Vesuvius in the great eruption of 79, and to have overwhelmed Pompeii and Herculaneum. This substance, however, has now become hardened into a compact tuff by the development of zeolites and other minerals in its substance, in precisely the same manner as Bunsen found that basalt, ground to a powder and left in water, consolidated, when the water evaporated, into a mass so hard as only to be broken with the hammer. Humboldt has recorded how the volcanoes of Ecuador have discharged torrents of mud so as to fill up valleys; and it is well known that the cone of Cotopaxi has repeatedly melted the great glaciers upon it, which descend to about 14,000 feet, and the water thus liberated has carried down the ash. The eruption of Imbambaru in 1691 poured out not only mud, but a considerable quantity of fishes, which would indicate that the crater of the volcano had become a lake, in which a species of *Pimelodus* had lived. In the geological formations, as will be subsequently seen, examples of forests buried in ashes, and vegetation overwhelmed by mud streams, are found among the primary rocks of Arran, and the tertiary rocks of Mull.

Bombs.—As the amount of steam becomes reduced, and the rock is less permeated by it, the explosive force in the volcanic throat is diminished; and the rock-material, though still blown out into cellular structure by the expansion of the steam, is ejected in much larger fragments, which are termed *lapilli* and *scoriæ*. At length the supply of explosive steam near to the surface becomes exhausted, and the fluid rock ceases to be shattered by its expansion. But from time to time fresh supplies of condensed vapour rise through the molten rock as it ascends, and catch up masses of lava, which are often rotated as they rise in the air, and become fashioned into the often rounded and sometimes hollow masses termed "volcanic bombs." These, however, are rarely thrown far, and usually occur near to the cone. But grander paroxysmal outbursts of steam have lifted large masses of

rock to a height of 25,000 feet, and some, thrown up from Heckla, have been seen by ships 180 miles out at sea. Humboldt speaks of masses weighing 200 tons ejected from Cotopaxi, while the plain around the volcano is strewn for many miles with great masses of lava which have been thus accumulated.

Lava Streams.—All this time the lava has been slowly rising in the volcanic throat; for in place of the pressure of superincumbent rock which formerly confined it, there is now no pressure above but the earth's atmosphere. The reduced pressure must operate on the liquid rock much in the manner of a pump; while below, there is the lifting power of the steam, which Bischoff states to be alone sufficient to expel the lava; and above all there is lateral contraction thrusting the rocks together so as to force the fluid to the surface. We need not now inquire into the height to which lava streams are stated to have been thrown; it is enough to recognise the fact that the molten rock rises in increasing volume. If the volcano is low, lava fills the crater till the stream overflows its rim, or bursts down its weakest side, and escapes like a torrent. If the volcano is high, fissures may appear on the flanks, and give exit to the molten rock, which then usually disappears from the crater.

The character of the lava stream depends upon the fluidity of the lava, the amount thrust out, and many circumstances of the eruption. When the streams are short they are frequently permeated with vapour, which expands the rock into a cindery mass; and as these vesicles burst on its surface, the rock acquires a rough or reticulated and stringy aspect. Such vapour cavities are always elongated in the direction in which the lava flows, and by their expansion help to arrest its movement. They usually disappear when the stream is large; and then the current, instead of dividing and subdividing as it descends, is apt to move irresistibly over all obstacles and spread itself in a wide sheet. In the last three centuries many lava streams from Vesuvius have reached the sea, frequently descending upon the town of Torre del Greco. In 1631 twelve or thirteen branches reached the coast in broad masses, and still cap the cliffs. Some of these streams were five miles long, and their extreme distance apart, on the coast, was seven and a half miles. Among other well-known streams in this district was the lava flow of 1794, one branch of which passed through Torre del Greco in a sheet 1130 feet broad and 15 feet thick, and extended 360 feet into the sea. The celebrated lava flow from Etna in 1669, issuing on the flank of the mountain, ran for fifteen miles, passing over part of Catania, and entered the sea in a mass 1800 feet broad and 40 feet thick. In Hawaii, some lava-flows are 25 miles long; in Iceland, streams from Skaptar Jokul have run for 60 miles; in Greenland, they are longer still, though even those are far surpassed by the great lava sheets of the west of North America.

Temperature.—The temperature of the lava is very variable. In the Vesuvian lavas the heat is above the melting point of silver, but does not always melt copper. A stream from Etna in 1766 in a

quarter of an hour melted down a hill of volcanic matter 50 feet high and carried it away. On the other hand, a stream from Kilauea in 1839, catching the branches of trees, scarcely scorched the bark, and the lava hung from them in masses like stalactites; while islets of forest trees were swept along on the surface, without killing the bamboos, and only partially injuring the foliage.

Rate of Flow of Lava.—The rate at which the lava flows is necessarily variable, but it may be remarked that the stream from Etna in 1669 ran 13 miles in the first 20 days, while it occupied 23 days in covering the last two miles. The fluid lavas of the Sandwich Islands have a far greater velocity, Dana stating the average progress of the stream of 1839 at 400 feet an hour.

Aspect of Lava Fields.—The island Hawaii exhibits in a striking manner some of the varieties which fields of lava assume on cooling. Large tracts consist of smooth solid lavas, with undulating ridges and hillocks some 10 to 20 or 60 feet high, and with the surface marked with folds and lines, such as may be seen on glassy slags. When the elevations are broken through, they are seen to be hollow, and due to the ascent of volumes of vapour, which have formed subterranean caverns. Other regions are rough, and termed "clinker fields." They are covered with angular blocks and rough slabs of every possible size, lying in the utmost confusion. These fields stretch for miles, and are characterised by a grey and black desolate condition. The transition from one surface of lava to the other is frequently abrupt. The clinker fields are supposed by Professor Dana to result from a lava stream floating on its surface, the materials of a stream which had cooled, in much the same way as ice is carried by a river in spring; and perhaps the fact that the clinker fields rise 20 or 30 feet above the smooth lavas favours this view. The fissures in lava streams are often seen to have been filled after the crust of the lava had cooled, so that miniature dykes are formed, and raised a little above the surface. This aspect characterises the whole of the southern and south-eastern part of the island, and is termed by Dana "the wearying grandeur of desolation." The European lavas are rarely smooth. They more frequently have an irregular billowy appearance, because the hardened external film is long carried on with the stream, and rolled over and over till the consolidated surface becomes extremely rugged. Professor Phillips observed that the hardened crust of the Vesuvian lavas sometimes forms tunnels, from which the lava may run out so as to leave an arched roof, which, however, soon falls in as the lava cools.

It seems probable that one cause of the fluidity of greatly heated lava must be its freedom from dissolved water, since steam, in expanding, can only tend to arrest its movement.

Surface of a Volcano.—The form of the mountain thus built up depends a good deal upon the nature of the ejected materials. Those cones which are formed chiefly of ashes are often regular and conical; while those formed chiefly of lavas are frequently so rugged as not to suggest at first sight a volcanic origin. The regularity, too, may

be a good deal influenced by the wind, which often blows the ash so that it accumulates more on one side of the mountain than the other. The steeper inclination is always towards the summit, where it may amount to 20° or 35°, the slope gradually diminishing down the flanks, till the level becomes horizontal. Volcanoes are often rendered irregular by the truncation of the cone, and by the development of parasitic cones upon their flanks. According to Sartorius Von Waltershausen, there are upwards of 700 minor cones on the flanks of Etna; and Dana mentions several thousand in the island of Hawaii. These minor cones (according to Mr. Scrope) vary in size from that of a hay-stack to 1000 feet in height, and two or three miles in circumference.

Cones and Craters.—All the time that the eruption is in progress, the volcano undergoes changes of form, partly from the accumulation of ejected materials on its flanks, partly from the building up of new lateral cones upon it. But more important changes are developed at the top of the mountain; for, as the super-heated water rises towards the surface, and flashes into steam in the throat, its explosive force blows out the loose materials of which the cone was composed; and thus the mountain becomes truncated, and its conical upward termination is often replaced by a funnel-shaped pit, which does not always become entirely obliterated by subsequent eruption. Thus, Monte Somma, on the flank of Vesuvius, is a remnant of the ancient crater, whose size marks the violence of its earlier eruptions. High up on Etna there is a somewhat flattened platform, which probably marks the limits of an ancient truncation of the mountain by the formation of a crater which has since been filled up; and upon which the upper cone now rises. A still grander example of truncation is furnished by Mauna Loa, which has a horizontal width of 20 miles at 18 feet below its summit. These great craters sometimes remain permanently as pits, and, according to Professor Milne, there are about 20,000 people dwelling in the crater of Asosan, in the island of Kiushiu in Japan. This crater is 15 miles in diameter. Many extinct volcanoes seem to have exhausted their energy in a final effort of this kind, which has blown much of the volcano into the air. Perhaps the most remarkable examples of large craters are seen in the crater lakes to the north of Rome. The lake Bracciano is nearly circular, 6½ miles in diameter, and its surface rises 540 feet above the sea. The crater of Monte Albano is 6 miles in internal diameter, almost entirely composed of volcanic dust, and has a central mountain in its midst. The lake of Bolsena is over 10 miles long by 9 miles broad, approximating to the oval outline common among craters. In its midst rise two islands, which are composed of volcanic tuffs, and show the characteristic quaquaversal dips which are seen in cinder cones; so that, large as these excavations are, and vanished as are the ancient volcanoes, we observe no more than extreme stages of truncation of the mountains by explosive forces, accompanied by faint indications of nature's efforts to restore the structures destroyed.

It is an almost universal experience, after the crater of a volcano has been thus formed, and the lava raised and poured out, that considerable quantities of heated water rise through the molten mass in the volcanic throat, and burst in great bubbles so as once more to throw up cinders, which fall around the throat and begin to build up a new cone within the crater. The views of Vesuvius published by Sir William Hamilton are particularly instructive in this connection. In 1756 this mountain possessed no fewer than three cones and craters, rising successively one within another, the outermost being girdled by Monte Somma. Then the innermost cone became obliterated, and finally, in 1767, but one cone existed within the crater, which in due time became filled up, so as to form a convex platform; until a new eruption, in 1822, blew out the entire centre of the mountain, and then once more small craters began to appear as the crater became filled up again. More than once, two or more minor cones have existed side by side within the crater of Vesuvius, as though a fissure had formed across its floor, and permitted the escape of the explosive forces along a line.

Volcanoes without Cones.—It is not always, however, that cinder cones are produced. In the summit crater of Mauna Loa, which is termed Mokua-Weo-Weo, there were at the bottom of the pit that serves as crater two cinder cones, one of them rising 200 feet in height when examined by Professor Dana. But the Sandwich Island volcanoes are remarkable for the absence of cones, in place of which there are deep pits on the side of the mountain, and the so-called cones are patches of lava which have been ejected on the flanks. Kilauea, which is sixteen miles from the summit of the mountain, has no cone, and the crater is a pit $7\frac{1}{2}$ miles in circumference.

Cones arranged in Lines.—Any one who carefully examines a volcano, or still better, a volcanic district, will observe that the position of the eruptive vent undergoes some change. Thus, in the island of Vulcano, there is the ancient crater which forms the S.E. of the island, with three other craters successively superimposed, before we reach the small mass on the north termed Vulcanello, which also has a succession of craters in a line. But it is more instructive to observe the manner in which cones succeed each other on a grand scale in such a chain as the Andes, or the Kurile Islands; for we may reasonably infer that the cause, whatever it was, which determined the shifting of the point of eruption along such a line as that of Vulcano, is closely analogous to the cause which determines the intermittent outbursts of eruptions along successive portions of a volcanic chain.

We have only to observe what has happened in the history of Etna to learn the secret of the linear extension of volcanic vents. After the central cone has become sufficiently massive and consolidated to oppose a resistance which the explosive forces below cannot easily overcome, they occasionally find an outlet by producing rents on the mountain-side. Rarely these rents radiate, but more frequently they are limited to one side of the mountain, and sometimes occur in parallel bands. Among numerous illustrations given by Ferrara, we

may remark that in 1536 a fissure of this kind was formed, along which 12 cones were erupted one below another. In 1669 the mountain was split from the summit down two-thirds of its extent, and from this fissure flowed the lava stream which destroyed Catania, while upon it was built up the great double cone known as Monte Rossi. On other occasions the lava has boiled out from fissures and formed streams, all in the same line, at a number of points successively below each other. Some of these fissures have been traced, and seen to be filled to a certain height with incandescent lava. One of the latest examples was formed in 1874, and described by Professor Orazio Silvestri,[1] who states that after the central crater had poured out formidable columns of black smoke, sand, and scoriæ, a fissure appeared on the north side of the central crater, which extended for five kilometres, running east by north, and at a height of 2450 metres was 50 to 60 metres wide where widest. Here a new elliptical crater formed, and at its base ten small eruptive throats succeed each other in a distance of 50 to 60 metres; then others follow, so that there are 22 minor cones in linear extension in a distance of half a kilometre, and lower down there are 13 more cones, many of them only a few yards in diameter. The superficial temperature of the lava streams erupted was 70° cent.; at a depth of half a metre it was 90° cent. This new mountain and its system of 35 subordinate cones and lava streams, were all thrown up in a few hours.

Fissure Eruptions.—These fissure eruptions vary greatly in importance. We have already seen that fissures on Etna may pour out lavas without passing them through a volcanic cone, but it may be useful to remember that this is the usual condition in Hawaii, and that the eruption is then on a grander scale. A stream issuing from a fissure in 1839, at a height of 1244 feet, flowed for twelve miles and ran down to the sea. For three weeks this fiery river continued to pour on, converting night into day. The reflected glare of the lava was visible 100 miles at sea, and fine print could be read at midnight at a distance of forty miles. When this lava entered the ocean, it was shivered into millions of particles, which were thrown up in clouds that darkened the sky, and fell like a storm of hail on the surrounding country. With such materials, it will be readily understood that lava-flows occur which are independent of ordinary volcanic activity. Indeed, Von Richthofen regards massive fissure eruptions as the more important and fundamental phenomena, conceiving that just as a minor cone may be parasitic upon a main cone, so the ordinary volcano is parasitic upon the subterranean part of a massive eruption.[2] But as a rule the massive eruptions form mountain-ranges and show no signs of craters, though volcanoes occur on their lower slopes, or form a parallel series of outbursts after the rock in the main fissure has solidified. In such cases the rock-material is the same in the massive outburst and in the volcano.

[1] "Notizie sulla eruzione dell' Etna, del 29 Agosto, 1874. Catania, 1874."
[2] "Natural System of Volcanic Rocks," Mem. California Academy of Sciences, vol. i. part 2, p. 66.

The kind of rock emitted varies with the district. In the Andes the bulk of the volcanic rocks consists of a dark or blackish rock termed Andesite, which is also seen on the southern slopes of the Carpathians. It forms the Hargitta range, the Vihorlat-Gietin range, and the Eperjes-Kaschau range. It is emitted from Chimborazo, Cotopaxi, Antisana, Tungurahua, Popocatepetl, Colima, Teneriffe, which are said never to have changed the mineral character of their lavas.

Other fissure eruptions on the Carpathians in Hungary and Transylvania consist of the dark volcanic rock termed Propylite.

Trachyte is still being ejected by most of the volcanoes of Central America. It forms the base of Etna and the older rocks of the Campi Phlegræi. It occurs in the Lower Rhine and Central France; and circles round the east of the Washoe Mountains.

Rhyolite, in Hungary, skirts the lower part of the Andesite ranges, and forms the Tokay Mountains. Vast sheets occur on the east of the Sierra Nevada.

Professor Joseph Le Conte states that the lava-floods of the Sierras commence in Middle California as immense but separate lava streams. In Northern California they become an almost continuous flood, which in Oregon is 2000 feet thick, and universally spread. It streams away to the north through Washington Territory, and on into British Columbia for an unknown distance. This lava inundation has a length of 700 to 800 miles; the stream is 80 to 100 miles broad, and where cut through by the Columbia River is 2000 to 3000 feet thick. It is one of the most remarkable results of fissure eruptions that is known.

Nearness of Volcanoes to the Sea.—If we refer to a map recording the distribution of active volcanoes, such as that given by Professor Karl Fuchs,[1] it will be observed that nearly all the volcanic regions of the earth are remarkable for their linear extension, and in this we may see evidence of their arrangement along fissures of great magnitude. And secondly, it may be noticed that with few exceptions they are situate either in oceanic islands or comparatively near to the sea. And when this distribution is compared with that of the great regions of extinct volcanoes, which are for the most part in the interior of continents, and far removed from the sea, we have strong presumptive evidence that volcanoes need for their activity more water than can usually be furnished from a sub-aerial source; for it would seem that as land is uplifted, and the volcano removed from the sea, its eruptive power usually disappears. But we are further compelled, by the theory of fissure eruptions, to conclude that the situation near the sea is not due to the action of water alone, but is a consequence of the ways in which the rocks, which undergo compression so as to rise in island chains and mountain ranges, are ever developing new fractures, parallel to the direction of their upheaval; and while this cause may develop new heat, and give access for new supplies of water to the region which is heated, it

[1] "Vulkane und Erdbeben," 1875.

renders the position of the volcanoes readily intelligible. Other agencies, such as the accumulation of sediments, have sometimes been supposed to develop additional pressure, and assist in augmenting the volcanic fires along coasts; but on the view proposed, we seem compelled to adopt the conclusion so long since enunciated by Krug von Nidda, and regard volcanoes in their normal condition as intermittent springs which throw out melted matters.

Relation of Volcanoes to Springs.—There is, in fact, a perfect sequence to be traced from the volcano which pours out molten rock to that in which the water supply has become so great, relatively to the rock-matter, that the materials ejected cease to be molten; and as the water preponderates they may become more and more invisible, till the condition of a hot spring is reached. Professor Prestwich has drawn attention to the fact that an artesian well at Naples, after passing through 735 feet of volcanic beds, and 787 feet of more or less water-bearing strata, furnished a spring which rose 8 feet above the surface, or 81 feet above the sea-level. He urges that the pressure of the water in the rocks which rise above the sea-level keeps the sea-water out from the land. But when the water which is stored in the mountain and neighbouring rocks becomes expelled and exhausted under the conditions of an eruption, then the pressure is removed on the landward side, and an inflow of salt water from the sea necessarily takes place, and modifies the explosive form of the outburst.

Decline of Volcanic Activity.—After the solid materials cease to be ejected, and before the eruptive throat of a volcano is hermetically sealed, the existence of various gases may be detected, and the deposition of salts observed. Some of the gases appear to be given off all through an eruption, others chiefly at its close. Among the most frequent acids are sulphuric and hydrochloric. The gases comprise nitrogen, hydrogen, and carbonic dioxide. When we seek for the causes of the gaseous eruptions, we shall find some gases to be derived from water, and others from the rocks beneath the surface. It is well known that a considerable amount of atmospheric air is dissolved in water, and that in sea-water there is some amount of carbonic acid gas; it is also known that at a moderate temperature these gases become expelled from water, and at a higher temperature the water itself is decomposed into oxygen and hydrogen. The hydrogen is chiefly found as sulphuretted hydrogen, and in combination with chlorine, in the form of hydrochloric acid; the nitrogen is more common in the form of sal ammoniac than in the free state. The decomposition of the sulphuretted hydrogen has produced frequent deposits of sulphur, which sometimes cap the mountain. The frequent presence of salt, of hydrochloric acid, and the large percentage of soda in Vesuvian lavas, leave little doubt that sodium chloride in some way obtains access to the heated regions, and in some cases is decomposed. The most abundant gas is carbonic dioxide, and this would appear to be always due to the action of heated matter upon limestones beneath the surface, so that the

gas is produced much as in a lime-kiln; and the fact that limestone fragments are ejected from Vesuvius leaves no doubt that the material exists where it can be calcined.

As the mountain cools and contracts, small cracks appear about its summit and its flanks. These are termed "fumeroles," and give vent to steam and various vapours, which deposit brilliantly-coloured crystals of salts, that are mostly soluble and are dissolved by rain.

The decline in eruptive power, however, is gradual, and at a lower level on the flanks of mountains new phenomena often appear, and testify to the changed condition of the interior regions.

Solfataras.—This is especially seen in the formation of solfataras, which are essentially hot springs wherein the dissolved acids decompose the rock through which the water flows, so that a good deal of mud is brought to the surface; and as the sulphuretted hydrogen in the water is decomposed, sulphur is deposited in the clay in nodular masses. Such sources of sulphur-supply occur at the solfatara near Naples, and in the deposits near Girgenti in Sicily, and in Iceland. Professor Ansted described some remarkable deposits and solfataras at Kalamaki, near the Isthmus of Corinth, where the sulphur-bearing region is about a mile long and half a mile wide. Not only are the marls loaded with sulphur, but it is deposited in a crystalline form from hot vapour, in gorges and caverns.[1]

Mud Volcanoes and Mud Springs.—Another phase of declining volcanic activity is exhibited in the formation of mud cones, which are common not only in the volcanic regions of Mexico and Peru, but in Iceland, and many localities in the South of Europe. Professor Ansted mentions a mud eruption which took place in a flat plain below Paterno, to the south-west of Etna, which threw out water in strong jets, without visible vapour, though large bubbles of carbonic acid gas arose through the muddy water. The temperature of the water at the surface was 110° F. The fluid ejected was a thin mud, which on exposure became a tenacious paste. A good deal of petroleum floated on the surface of the water, and the neighbouring volcanic rocks contain cavities full of naphtha, and have a strong bituminous odour. Mud volcanoes are much more numerous on the eastern side of the Crimea, reaching for about 50 miles from the straits of Kertch. The cones about Yenikale pour out mud slowly from the top. The fluid has a temperature of from about 55° to 65° F. It is tenacious, often as thick as treacle; and the streams, which are blackish when dry, sometimes run for about 120 feet. The largest hill, near Kertch, is about 250 feet high; and the main cone consists of clay, in which are embedded small angular pieces of limestone and fragments of earthy oxide of iron.[2] Other examples occur in North Italy, in Parma and Modena. But among the most interesting are those discovered by Captain Stiffe [3] on the Mekran coast, which stretches

[1] Ansted, Q. J. G. S., vol. xxix. p. 360; and Th. Fuchs, Verh. K. K. Geol. Reichsanst: 1876, p. 54.

[2] Royal Institution, Friday, May 11, 1866.

[3] Quart. Jour. Geol. Soc., vol. xxx. p. 50.

from Scinde to the mouth of the Persian Gulf, and are most numerous in its eastern portion. Their situation is remarkable from the circumstance that, there are no traces of volcanic action on the coast. They extend over 200 miles from Guadur to Ras-Kucheri, and vary in height above the plain from 20 feet to 400 feet; they are truncated at the top, and have circular craters, in some cases 100 feet wide. Here the mud is cold, somewhat thicker than treacle, and consolidates into a compact substance. From time to time there is an ebullition of gas. The mud ejected is chiefly clay, with some carbonate of lime and a little quartz sand. Thus we remark a decline in temperature, until there is no external indication of volcanic action, except the form of the cone and its eruptive character. But there are other modes of volcanic decline in which mechanically-suspended substances are never brought to the surface, and the erupted matters are bituminous products or mineral and metallic matters in solution.

Petroleum Springs.—Asphalt is constantly met with in connection with mud volcanoes. It may be sometimes absent (as when Humboldt visited the cones of Turbaco, near Carthagena in New Granada, in 1801), and yet found plentifully fifty years later. In other districts the discharge of asphalt or petroleum is permanent. Pallas and other travellers have described the presence of bituminous substances in the materials thrown out from the mud volcano of Taman, in the Western Caucasus; but probably the best known locality is Baku,[1] on the south side of the Caucasus, in the Caspian Sea. Here the ground is so saturated with petroleum that it is obtained by sinking wells; and Eichwald has remarked that the neighbouring cones should rather be called naphtha volcanoes than mud volcanoes, since the outburst always ends with a large emission of naphtha. Occasionally the naphtha, which floats on salt water, takes fire during an eruption, and the flames rise to some height. In the springs near Balachana the naphtha is derived from Upper Tertiary sandstones; but here, as in so many other localities, they exist in the neighbourhood of volcanic rocks. In the Dead Sea, the asphalt has been described by Lartet, and its appearance is associated with thermal springs in a region of old volcanic action.

In the island of Trinidad we see another phase of emission of asphalt in the celebrated Pitch Lake, which covers an area of 99 acres, and in the pitch banks which sometimes exist off the coast in that island; for here eruptive phenomena are entirely absent, except in a few mud volcanoes scattered over the country.[2]

The origin of the bituminous matter is not easily accounted for. Professor Ansted mentions a portion of a tree in the condition of lignite obtained from one of the mud volcanoes of Northern Italy; and the constant association of these springs with districts of tertiary

[1] See Abich, "Mémoires de l'Académie, Imp. St. Pétersbourg," viii. Série, tome vi., No. 5. 1863. Trautschold, Ueber die Naphtaquellen von Baku, "Zeitschrift der Deutschen Geolog. Gesellschaft," xxvi. Bd. p. 257. 1874.

[2] See Wall, Geol. Survey, Trinidad, where a belief is expressed that the mineral pitch is formed on the surface, out of existing vegetation.

coals evidently suggests that they are a consequence of the action of subterranean heat upon vegetable matter which happens to be contained in the strata. And this view is strongly supported by the fact, that during the explorations of the *Challenger* certain hot springs at Furnas in the Azores were visited by Professor Moseley, in which the algæ became converted by the heat of the water into a green, creamy, or black elastic inflammable substance.[1] And just as the mud volcanoes bring to the surface fragments of various rocks, so in the naphtha and similar materials we have a product which might naturally be associated with such strata. Indeed, the petroleum springs of the coal region of North America sufficiently prove that, given the vegetable matter and even such a moderate temperature as might result from the crumpling which the carboniferous rocks have undergone, there is no difficulty in obtaining the petroleum by a process of slow distillation. The special interest, however, of the naphtha springs is twofold, and lies partly in their normal existence in regions where volcanic action is nearly extinct, and in the extent to which they have in former times contributed to form bituminous limestones and deposits like the asphalt of the Val de Travers and many localities in Switzerland and France.

Eruptive Hot Springs.—Geysers offer another phase of volcanic action in which the eruptive power remains, but instead of the water being dissolved in the rock, or mechanically mixed with it, only such mineral matters remain as can be dissolved in the water. These phenomena mark the near extinction of volcanic energy, and not only originate near to the surface, but appear to owe their existence entirely to surface waters. It is remarkable that these phenomena, though met with in regions so widely separated as the northern island of New Zealand, the Yellowstone Valley in the United States, and the south-west of Iceland, exist in areas occupied by rhyolitic rocks.

Geysers of Iceland.—In Iceland they are chiefly found in the Reykiadal, about thirty miles south-west of Heckla, and are situate in an oblong strip of land where the marsh terminates and the mountains begin to rise. The water is furnished by cold streams derived from melting snows, and from the neighbouring river. The geyser basins are conical siliceous domes, built up of the material deposited by the waters as they cool. One of these has a height of 7 feet, and is 75 feet in circumference, while the eruptive throat in the centre of the basin is a circular opening 14 inches in diameter. Frequently these cones stand upon coloured clays, and they are so intimately connected with mud eruptions that in some places mounds occur, formed entirely of clay, from which water is thrown into the air to a height of a few feet. The well-known Great Geyser has a well-defined cone under the hill on the north-east side of Geyser Island; but the Strokr has no cone,

[1] "On Freshwater Algæ at the Boiling Springs at Furnas," &c., H. N. Moseley, Jour. Linn. Soc., vol. xiv., No. 77, pp. 322, 325, 333; also W. T. Thistleton Dyer, p. 326.

its mouth being on a level with the surface of the ground. The Great Geyser only ejects water once in twenty or thirty hours, throwing up a column 60 feet high, accompanied with clouds of vapour. The Strokr may be caused to erupt at any time by artificially blocking its throat, and its outbursts have lasted for half an hour at a time. But the phenomena change from time to time. In the middle of the eighteenth century there were three or four eruptions in a day, and some reached a height of 300 feet. Their activity is influenced too by earthquakes; and it is remarkable that no mention of geysers is found in the old Icelandic writings. When the geyser basin is full, the water is clear and in a state of ebullition, the temperature being about the boiling point, but Bunsen found that in the descending tube the temperature increased to 266° F. It would hence seem that the water draining in from the neighbouring hills has its temperature augmented by contact with heated rock, or water coming from heated rock, until a portion of the mass is so far raised in temperature that the water there, having boiled off the gases held in solution, overcomes the pressure of the column above, and bursts into vapour, so as to throw up the column above it in a fountain. The fact that Bunsen was able by experiment to reproduce periodic eruptions from a tube by heating its middle portion, goes far to demonstrate the accuracy of his interpretation, though the details of nature's mechanism beneath the surface are necessarily unknown.

Geysers of the Yellowstone.—All over the great lava district of the far west of North America geysers are numerous, though many are extinct. They are specially instructive, since they are often surrounded by mud volcanoes, and associated with calcareous springs, which have deposited limestone terraces, so that all the constituents of water-formed rocks are here differentiated, and poured out from neighbouring vents, though the materials are in some cases mixed. On the Yellowstone Lake the geyser called "Fishpot" is so close to the water that, without moving, the fisherman has caught trout in the lake, and cooked them in the boiling geyser. The Grotto and Giant Geysers of the Yellowstone throw up columns of water from one to two hundred feet high, and the eruptions last from one to two hours. A mud geyser in this district, at Crater Hill, has a small basin, 60 feet in diameter, formed chiefly of layers of clay and silica, situate in a larger basin with a higher rim, which measures 200 feet by 150 feet; and on one side of the outer basin is a ravine with holes in the banks, which are lined with sulphur. The geyser basins on the Firehole river are upwards of 7000 feet above the sea; they are rarely conical, more frequently globular, and often have overhanging ledges. The Grand Geyser throws up a column 6 feet in diameter and 200 feet high.[1] The temperature of the water is usually below the boiling point, and the water itself is green. Many mineral substances have been detected in these geyser waters, and among others small crystals of gold.

[1] See Professor F. V. Hayden, U.S. Geol. Survey of Montana, 1871, and Montana, Idaho, Wyoming, and Utah, 1872.

Geysers of New Zealand.—The geysers of New Zealand are in some respects much less interesting. They extend over a line of fracture in the Northern Island, which lies between the crater of Tongariro and the crater of White Island in the Bay of Plenty. Here geysers rise over a distance of about 17 miles, associated with hot springs, which come up through rhyolitic rocks, formed of hornblende and sanidine felspar. Most of the waters are alkaline, owing to the quantity of soda which they contain, and there can be no doubt that the silica in them has been dissolved from out of the volcanic rocks. The temperature of these waters varies from 80° to 200°. Many of the smaller geyser springs throw up water to a height of 30 or 40 feet. Some of the basins fill in ten minutes, and are in eruption every two hours. The best-known geysers are on the lake Rotomahana. One forms a hill above the lake, with a basin 100 feet in diameter and 15 feet deep, terminating in a pipe which is 8 feet wide. Its waters are of an intense sapphire blue, and as they descend, form successive milk-white or pinkish terraces of silica, in which the water gradually loses its intensity, and passes through a turquoise colour in the middle terraces, to a faint blue tinge at the base, where the overflow passes into the warm lake. When the silica is deposited, according to Von Hochstetter, it is at first as soft as gelatine, and gradually hardens into a mass which has a sandy texture and chalky aspect, but is frequently infiltrated so as to resemble chalcedony or opal. Fumeroles abound all over the geyser region, and there are occasional minute mud volcanoes 3 to 4 feet high. So near to the surface are the heated springs that they can often be tapped at will by pushing a walking-stick into the ground.[1] Extinct geysers occur in the Azores; and the sinter deposits there have preserved leaves of trees perfectly.

The Boracic Acid Jets of Tuscany.—About 15 miles S.W. of Volterra many jets of vapour, charged with boracic acid, rise from a narrow valley in the secondary limestone. Mr. Hamilton[2] describes large fissures which have in this way been filled up by deposits of calcareous sinter. By passing the vapour through water the boracic acid is collected, and the water is then evaporated. Similar discharges of vapour occur in the neighbourhood at Sarrezano, Castelnuove, and Monte Rotondo. The vapour escapes from hundreds of vents often with the noise of a steam boiler blowing off its steam.

Hot Springs.—Hot springs are by no means limited to volcanic regions, but they are most numerous where igneous rocks have been intruded.[3] Therefore we regard them as indicating that surface waters have penetrated to a depth where the rocks are still heated, and thus warmed, have risen again to the surface by different channels. Among the best-known examples in Europe are the sulphurous springs of Aix-la-Chapelle (171° F.), the springs of Ems (131°), Wiesbaden

[1] Hochstetter, "New Zealand: its Physical Geography, Geology, and Natural History."

[2] Hamilton, P. Geol. Soc., 1844, p. 477.

[3] See Daubeny's "Volcanoes," 2d ed., p. 544. 1848.

(147°), Tœplitz (117°), Carlsbad (164°), Baden-Baden (153°), Gastein (117°), Aix-les-Bains (116°), Leukerbad (124°), with many more in Central France, the Pyrenees, Hungary, Italy, and other countries. For the most part these springs are at moderate elevations above the sea, Wiesbaden being 323 feet and Aix-la-Chapelle about 500 feet; but at Gastein the spring rises at 3100 feet, and at Leukerbad at 4400 feet; while in South America hot springs occur in Chile at a height of upwards of 12,000 feet. Bischoff[1] has ingeniously calculated that by supposing water to collect on the Balm Horn above the Baths of Leuk at an elevation of 10,292 feet, where it is assumed to be liquid, it would, by flowing down the clefts in the interior of the mountain, be raised to a temperature of 125° F. on reaching Leukerbad, supposing the temperature to rise 2¼° F. for every 145 feet descended. Therefore, the temperature of hot springs is never above that which may be derived from the earth; but their existence in regions of existing and former igneous action may well be compared with the positions of geysers. Some, like the hot springs of Bertrich, slowly decline in temperature; and earthquake disturbance has raised the temperature of others. The substances dissolved in hot springs vary with the nature of the rocks through which the water flows, and with the temperature.

The evolution of gas is often considerable. It is commonly carbonic acid, as in nearly all the springs of volcanic districts, and those which rise through faults, or else it is sulphuretted hydrogen. Often there is a large evolution of nitrogen, as in the waters of Bath, Buxton, and many continental springs. Frequently the waters are so charged with carbonic acid as to form natural soda waters, and sometimes carbonic acid escapes from fissures without any indication of springs, as in the Mofettes, near Laach, and Gerolstein, and many localities in Italy. The salts dissolved in the waters of springs are usually carbonates and sulphates, but chlorides, phosphates, and fluorides are also found. The waters of Carlsbad (which contain about 463 grains of solid matter to the gallon) yield as the principal substance sulphate of potash, but there are small quantities of arsenic, iodine, bromium, antimony, gold, copper, chromium, manganese, zinc, cobalt, nickel, titanium, barytes, strontian, lithium, fluorine, selenium, phosphoric acid, and boracic acid, besides several organic acids and traces of resinous substances.

The hot springs of Cornwall at Wheal-Clifford, near Redruth, yield a large quantity of lithium, and are rich in chlorides of sodium and calcium. Professor Daubeny[3] has given a statement of the salts found in the principal thermal springs in a tabular view, from which it will be seen how variable are the salts contained, and how different are the geological formations through which the waters rise. But, in every instance, the conclusion is forced upon us that these salts are to a large extent such as would be yielded by the decomposition

[1] Bischoff, "Physical, Chemical, and Geological Researches on the Internal Heat of the Globe." 1841.

[2] Lyell Address, Brit. Association, Bath, 1864, p. 65.

[3] "Volcanoes," 2d ed.

of the various felspathic and micaceous minerals, which enter into the composition of igneous and metamorphic rocks.

We thus observe that springs differ from volcanoes in bringing to the surface soluble substances, one of which usually predominates in a particular spring; but if we regard hot springs, geysers, and mud volcanoes as a group of phenomena closely connected, we shall find in their waters all the materials which go to form the minerals that build up igneous rocks, or which are differentiated in lavas.

Relation of Hot Springs to Mineral Veins.—It is impossible in examining the analyses of the waters of springs not to be struck with the frequency with which they contain small percentages of copper, tin, zinc, iron, and other metals; and since it is well known that the salts which they commonly bring to the surface are deposited as the temperature decreases, so it has been inferred that the heated waters have dissolved the metallic substances which were contained in large masses of rock, and making their way from great depths into channels which communicate with the surface, have lined the walls of these fissures with crystalline deposits of metals, which have become separated from each other in consequence of the differences of temperature at which the different crystals are deposited. These are presumed to have formed on the walls of the fissure in successive layers, because the rock would always be colder than the water it contained; and thus it is conceived that the minute traces of metallic substances which sometimes come to the surface, are but indications of larger deposits of the same mineral, which the water of the spring parts with at greater depths beneath the earth's surface. And it deserves to be remembered that in regions where mineral veins are found to be divided by fissures of a later date, which also contain the ores of metals, the newer veins yield different metals and minerals to the older ones, as though the plane of denudation of the present surface of the earth had cut these deposits transversely at different distances from the source, or in positions where the temperatures of deposition were different. The deposits from hot springs at the surface are chiefly alkaline salts, and salts of magnesia and lime; but in mining districts, where mineral veins occur, we have in almost all cases evidence, not only of igneous action, or metamorphism and disruption of strata, but also proofs of enormous denudation. So that it is reasonable to conclude, especially with the experience of important metalliferous deposits occurring in gravels, that the upper portions of many mineral veins have been removed by denudation; and it is thus that we come upon the ores of metals in veins, which have neither been erupted nor volatilised from below, but simply segregated under the influence of water and volcanic heat, from the rocks in which they were previously diffused.

Denudation of Volcanic Regions.—Any area in which volcanic phenomena are manifested with the greatest intensity, always shows indications that the region has undergone extensive denudation. We need but to examine such sections as have been drawn across the

Andes by Charles Darwin [1] and David Forbes [2] to recognise in the vast inversion and incessant crumpling of the rocks, demonstration that before the era of existing volcanic activity, enormous, almost inconceivable, denudation must have taken place. This denudation, which has bared the granitic rocks and exposed the rich metalliferous veins at the surface, has reduced by no infinitesimal amount the weight of superincumbent rock which had to be rent to form the lines of volcanic fracture, and has lessened the height to which volcanic forces heaved the products of their energy.

The same phenomena may be observed in all volcanic regions, so that the manifestations of volcanic action which we have been considering may be held to depend not only upon the internal heat of the earth, but also in some degree upon the agencies which act upon its surface.

In the previous chapter we examined the ways in which heat acts upon and changes the surface rocks; we have now seen the nature of the changes which are produced on the materials thus altered by agencies at the earth's surface, and it only remains to inquire how far an examination of the products of volcanic action justifies the interpretation which has been here given.

[1] "Geological Observations on South America."
[2] Q. J. G. S., vol. xvii. p. 7.

CHAPTER XIV.

THE NATURE AND ORIGIN OF IGNEOUS ROCKS.

When we contemplate the products of igneous energy, as seen in lavas, dykes, and the materials of mountain masses, we are impressed by their diversity. From Vesuvius alone Von Buch distinguished eighteen distinct principal kinds of lava, besides many varieties; and the number of minerals found on this volcano forms a considerable fraction of those of the whole world. It has always been difficult to account for the variety of igneous rocks; and hence many hypotheses, from time to time, have been suggested in elucidation of observed facts. There are three principal views, all supported by a large amount of evidence, which are more or less worthy of attention, since they have been adopted by able observers.

Hypothesis that the Earth's Crust is formed of Layers of Different Igneous Rocks.—First, there is the hypothesis that all igneous rocks are derived from the more or less liquid interior of the earth. In its crude form, as stated by the earlier writers, this view had but little to recommend it, beyond its obvious simplicity. But when the observed facts of basaltic lavas being in many cases poured out after the trachytic lavas, as determined by Bunsen and earlier writers, became generalised into the hypothesis of the existence beneath the surface of two shell-like layers of rock material, the doctrine acquired importance; for the outer layer was assumed to be formed of highly silicated or acidic rocks, of lower specific gravity, and more perfectly oxidised, than the deeper-seated basic layer, which was inferred to have been extruded after the acidic layer had been poured out and cooled.

Subsequently, when Von Richthofen divided volcanic rocks into five groups, it became necessary to admit the idea of five of these magmas, forming successive shells or onion coat-like layers of the original fluid earth, which had been successively erupted. And when we bear in mind that this classification of lavas into propylite, andesite, trachyte, rhyolite, and basalt, represents the order in which they are superimposed upon each other in Hungary, Transylvania, North Germany, and the great volcanic region of North America—an order which experienced geologists have found never to vary—there is an *à priori* case in favour of thus accounting for the diversity of igneous rocks. But we need to bear in mind that this sequence, even if it should hold good for larger areas than those in which it has been established, is, at best, an order which characterises certain eruptions of the tertiary period; and the moment we go further back in time, the

illusion vanishes, as Von Cotta clearly saw; for instead of finding other zones, or magmas of the earth's substance tapped by ancient outbursts of the secondary and primary periods, we still meet with rhyolites, basalts, trachytes, and andesites; but in an order of succession in time which bears no relation to their occurrence in Richthofen's tertiary system. We therefore are compelled to abandon the hypothesis that volcanic rocks are derived from the original products of an igneous fusion of the earth; and no law has ever been suggested which would on this hypothesis, show that the order of their successive appearance in the Primary period could be harmonized with their order in the Tertiary period. It is an attempt not to disentangle and explain the problem, but to escape from it by assuming results supposed to follow from original igneous fusion of the earth.

Chemical Hypothesis of Davy and Daubeny.—Another view which cannot be altogether ignored is the chemical theory, originated by Sir Humphrey Davy, modified and supported by Daubeny, and combated by Bischoff. This conception, also starting from an original igneous fusion, rested on the hypothetical idea, that the interior of the earth consisted of the elements in an unoxidised condition; and as water and the atmosphere obtained access to these substances from the earth's surface above, so chemical changes were assumed to be developed, which gave rise to volcanic energy. We need not now delay to examine this view in detail. The potency of chemical action to produce important changes in rock materials, and possibly in the relative level of land, may be regarded as established; but when we remember the demonstrated continuity of volcanic outbursts with plutonic phenomena, we seek in vain for any evidence which would allow us to believe that the internal heat of the earth, crystallisation of igneous rocks, and eruption of lavas, are exclusively or even primarily chemical processes.

Hypothesis of Igneous Evolution.—Finally, there is the hypothesis which regards all igneous rocks as metamorphosed from ancient sedimentary strata, in the manner indicated in a previous chapter. This may be termed the hypothesis of igneous evolution, which supplements the hypothesis of organic evolution. For since the most ancient fossiliferous rocks contain highly-organised groups of animals, and even genera which still survive, we are compelled to believe, if the hypothesis of organic evolution is true, that strata immensely more ancient than those preserved must have existed, and represented long eras of past time, during which the earlier steps of organic evolution took place. And since no such rocks have been found, a belief in organic evolution enforces the conviction that such strata were metamorphosed, worn into sediments once more, and metamorphosed again, with many repetitions of the process, effacing from the earth all traces of its ancient life in times antecedent to the Primary era. The evidence on which this conclusion rests is essentially palæontological; but it will be sufficient to restrict ourselves now to the observed facts of igneous outbursts, and see how far the origin of igneous rocks can be explained on this hypothesis.

Views of Sir John Herschel.—It is to Sir John Herschel that we must attribute the enunciation of the origin of volcanic and igneous phenomena in metamorphism of sedimentary deposits. In 1836 he maintained that the temperature of the earth's crust must be raised in consequence of the accumulation of sediments, and insisted that the heat thus developed in the strata would result in the development in them of a crystalline condition, and that, under the influence of included water, they might become heated to the melting point, so that gases would be given off, and the phenomena of earthquakes and volcanic eruptions result. He further appealed to the transfer of sediments by denudation, as the primary cause which has initiated internal changes which result in elevation and depression of the earth's crust. As late as 1861, we find this distinguished philosopher urging, in his "Physical Geography," that the accumulation of sediments, and their denudation, is capable of producing any amount of pressure on the one hand, and relief from pressure on the other, that the geologist can possibly require, without calling in the aid of unknown causes.[1] These views, however, in so far as they concern the recognition of pressure and water as agents in volcanic action, were anticipated by Poulett Scrope in 1825;[2] and in so far as concerns the nature of the products of metamorphism of sedimentary rocks, identical views were published by Keferstein in 1834. But these hypothetical ideas produced little or no impression, and were propounded anew by Sterry Hunt.[3]

Views of Sterry Hunt.—Hunt's views are similar to our own, which were suggested by other evidence. They are well stated in the following paragraph:—

"Two things become apparent from a study of the chemical nature of eruptive rocks; first, that their composition presents such variations as are irreconcilable with the simple origin generally assigned to them; and, second, that it is similar to that of sedimentary rocks whose history and origin it is, in most cases, not difficult to trace. I have elsewhere pointed out how the natural operation of mechanical and chemical agencies tends to produce among sediments a separation into two classes, corresponding to the two great divisions above noticed. From the mode of their accumulation, however, great variations must exist in the composition of the sediments, corresponding to many of the varieties presented by eruptive rocks. The careful study of stratified rocks of aqueous origin discloses, in addition to these, the existence of deposits of basic silicates of peculiar types. Some of these are in great part magnesian, others consist of compounds like anorthite and labradorite, highly aluminous basic silicates, in which lime and soda enter, to the almost complete exclusion of magnesia and other bases; while in the masses of pinite or agalmatolite rock we have a similar aluminous silicate, in which lime and magnesia are wanting, and potash is the predominant alkali. In such sediments as

[1] *L. c.*, p. 117.
[2] See "Considerations on Volcanoes," by G. Poulett Scrope. 1825.
[3] "Chemical and Geological Essays," 1875, pp. 8, 15, 44, 66.

those just enumerated we find the representatives of eruptive rocks like peridotite, phonolite, leucitophyre, and similar rocks, which are so many exceptions in the basic group of Bunsen. As, however, they are represented in the sediments of the earth's crust, their appearance as exotic rocks, consequent upon a softening and extravasation of the more easily liquefiable strata of deeply buried formations, is readily and simply explained."[1] No other interpretation gives so simple and logical an explanation of the variety of lavas which volcanoes emit.

Texture of Volcanic Rocks.—In any endeavour to comprehend their variety, we are always thrown back from considerations of texture and mineral structure to the fundamental facts of chemical composition. The texture of lavas may be nearly paralleled by that of iron-furnace slags; and we have seen at the Lowther Iron Works at Workington, slags which have run their full length exhibiting a compact earthy fracture and deep blue colour, while other portions of the flow which have descended like the waters of a cataract, have consolidated into stalactitic sheets and films of nearly transparent glass; while in one portion of the stream, where the slag had overrun a minute spring, the whole mass was elevated into a cone of yellowish white cavernous pumice, with a well-defined cup at the summit. And occasionally, under special conditions, these slags are found perfectly crystallised, with a development of Humboldtilite and other minerals. This circumstance, no less than the differences seen in extinct volcanoes between the texture and the mineral composition of lava streams, and the parent masses from which they were poured out, seem to render any purely mineralogical classification impossible. And it has been experimentally proved that slight changes in the chemical composition of the mass necessarily result in the development of different minerals. We therefore proceed to examine the origin of granite as a type of the history of igneous rocks; because if the hypothesis of igneous evolution can be applied to granites and rhyolites, we make no doubt that its application to other igneous rocks must follow.

Origin of Granites.—It is convenient first to turn our attention to the granites, and the lavas which most nearly correspond to them in composition because they are perhaps the best known. Not only do granites vary greatly in the relative proportions of their mineral elements, but they also exhibit considerable variation in their constituent minerals. For although we may use the general formula of quartz, felspar, and mica to describe the rock, yet the felspar or mica may be almost any member, or members, of these families of minerals, and they may be supplemented or partly replaced by minerals which are no essential component of granite, and are local in their development. And when the chemical composition of granite is examined, the variation is almost as remarkable; for although we may regard the normal composition as including silica, alumina, peroxide and protoxide of iron, lime, magnesia, soda and potash, and water, yet

[1] See also Clarence King, U. S. Geol. Exploration, Fortieth Parallel, vol. i. p. 112, on the "Genesis of Granite and Crystalline Schists."

sometimes in addition to these there are perceptible quantities of oxide of manganese, phosphoric acid, lithia, and fluorine, while not infrequently the protoxide of iron, or even all the iron, may be absent, as may be the magnesia and the water. Even in British granites the percentage of every constituent is very variable; thus the silica ranges from as low as 55·20 in the granite of Ardara to as high as 80·24 in the granite of Croghan Kinshela; so that, judged by this test, the Ardara rock might be termed basic, while the Croghan Kinshela rock is typically acidic.

The alumina varies from 11·14 per cent. at White Gill, Skiddaw, to 20 per cent. in the granite of Glen in Donegal. The peroxide of iron ranges from ·23 at Botallack, to 7·3 in some of the granites of Leinster; while the protoxide of iron which is so frequently absent, amounts sometimes to upwards of 2 per cent. The lime varies from ¼ per cent. in some of the Cornish granites, to upwards of 5 per cent. in some of those from Donegal. The magnesia, which may be a mere trace, amounts to 3½ per cent. in the granite of Ardara. Soda may be but ½ per cent. in Cornish granites, and 5½ per cent. in some of the Leinster rocks. Potash is less than ½ per cent. in one of the Leinster granites, and more than 8½ per cent. in the granite of Chywoon Morvah in Cornwall. The manganese never quite amounts to 1 per cent., and the water is never more than 2 per cent. If we further included the elvans in our survey, we should find in some respects yet greater variations, since the percentage of silica may fall as low as 47, and the water and magnesia rise above 6 per cent. each.

Turning from the examination of these rocks to discover deposits out of which they might have been formed by metamorphism, we have not to seek far. We may take such clays as are associated with the coal strata, or used in the potteries, and find their composition to include the same chemical elements as granite, though from the analyses available, we may not be able to exactly parallel the granite of any particular district. These clays consist of silica, alumina, peroxide, and occasionally protoxide of iron, lime, magnesia, potash, and sometimes soda, and water; while occasionally there are traces of phosphoric acid, organic matter, and various elements locally distributed. If we further compare the percentages, we shall find the silica to vary between 44 per cent. and 77 per cent., while the alumina varies between 14 per cent. and 34 per cent. The lime may be less than ¼ per cent., or as much as 3 per cent.; the magnesia rarely exceeds 1 per cent. The potash ranges as high as 3½ per cent., and the soda, which is not often detected, is in some cases ½ per cent., while the water may vary from 1 per cent. to 25 per cent. These facts may be seen sufficiently set out in the accompanying tables, which give the chemical compositions of certain clays. First we compare the granite of Creetown with a slate from Prague analysed by Zirkel, and detect but little more difference than might occur in different samples of the same rock. The Cornish granite of Redruth may be compared with the American triassic sandstone of Cottonwood. If this granite is compared with the clay of Hillscheid or

Comparison of the Composition of Granites and Clays.

	Creetown Granite.	Prague Slate.	Redruth Granite.	Cottonwood Sandstone.	Bendorf Clay.	Hillscheid Clay.	Löss.
Silica	67·04	67·50	74·69	74·74	75·44	77·03	78·61
Alumina	17·20	15·89	16·21	14·14	17·09	14·06	15·26 (Alumina and Peroxide of iron)
Peroxide of iron	3·15	5·85	1·16	·79	1·13	1·35	
Protoxide of iron	·41	...	...	...	...	...	...
Lime	2·92	2·24	·28	1·61	·48	·35	...
Magnesia	1·20	3·67	·48	·39	·31	·47	·91
Soda	3·25	2·11	1·18	·92	...	...	3·33 (Soda and Potash)
Potash	3·90	1·23	3·44	5·29	·52	1·26	
Manganese oxide	...	...	·58	...	...	...	...
Lithia	...	...	·10	...	...	...	...
Water	...	...	1·23	1·88	4·71	5·17	1·89

Bendorf, it will be seen that the chief differences between them are that the granite contains some soda not found in the clay, and three times as much potash, while the clay contains much more water than the granite. These differences are small compared with those seen in different so-called granites, though they would determine distinct felspar formation. The percentage of lime and magnesia in clays must necessarily vary with the organisms clays contain, so that the only difficulty which presents itself exists in the small percentage of soda and the large percentage of water. Some alum-shales in Sweden contain 3 to 8 per cent. of potash, and some are free from water. From the fact that crystals of sodium chloride are met with in purbeck, triassic, and carboniferous clays in this country, the deficiency of soda is not perhaps insuperable, even without appealing to probable sources of salt supply, in the contact of sea-water with heated regions beneath the earth's surface, or growth and decay of marine plants. And the presence of combined water in clay, though greater than the quantity which is found in granite, is perhaps not more than we may assume would be easily expelled or altered by chemical combination, under the conditions of igneous fusion, since it often disappears in slates. If, then, it is no rare circumstance for certain sandstones and clays to have an average chemical composition which is nearly identical with that of granite, we may fairly believe that such strata,[1] under requisite conditions of heat, pressure, and cooling, such as would be presented in the central axis of a mountain mass, would become changed by metamorphic action into granite rock.[2]

[1] See pp. 206 and 210.

[2] It may not here be out of place to draw attention to the celebrated instance at Carlingford, in which Dr. Haughton affirms that veins of granite penetrating into carboniferous limestone become converted into syenite, by assimilating a certain portion of the limestone. Mr. R. H. Scott confirms Dr. Haughton's determination, so that the facts may be presumed to be clear; yet we cannot help drawing attention to the circumstance that the Carlingford granites all contain 7 to 8 per cent. of alkali, and Dr. Haughton's analysis gives no trace of alkali in his syenitic rock. Such a result would not have been anticipated from adding limestone to granite substance under such conditions.

	Analyses of Foreign Clays.								Analyses of British Clays.						
	Passau Clays.[1]					Fire Clays.[2]			China Clays, &c.[3]						
	Hillscheid.	Bendorf.	Baumbach.	Greuzhausen.	Eberuhahu.	Clay above Chalk. Houdan (Seine-et-Oise).	Hessen Cassel.	Near Carlsbad.	Howths near Dublin.	Cornwall China Clay.	Poole Dorset.	Newcastle Coal Measures.	Stourbridge.	Bovey Tracey.[4]	Bovey Tracey.[4]
Silica	77·03	75·44	62·78	68·28	64·80	44·50	47·50	58·39	74·44	46·32	48·99	55·50	65·10	67·5	47·0
Alumina	14·06	17·09	25·48	20·00	24·47	53·00	34·37	27·94	19·04	39·74	32·11	27·75	22·22	29·0	48·0
Peroxide of Iron										0·27	2·34		1·92	1·0	1·5
Protoxide of Iron	1·35	1·13	0·25	1·78	1·72	1·91	1·24	trace	0·61			2·01			
Lime	0·35	0·48	0·36	0·61	1·08	1·34	0·50	2·74	0·45	0·36	0·43	0·67	0·14		...
Phosphoric Acid	...	...	...	...	...	...	...	...	...	...	...	...	0·06		...
Magnesia	0·47	0·31	0·47	0·52	0·87	0·60	1·00	1·00	0·27	0·44	0·22	0·75	0·18	1·5	2·0
Organic Matter													0·58		
Potash	1·26	0·52	2·51	2·35	0·29	...	traces	...	2·07	...	3·31	2·19	0·18	...	...
Soda	...	...	...	...	...	trace	...	...	...	...	...	0·44	...	...	...
Water	5·17	4·71	6.65	6·39	6·72	12·87	0·43	0·49	3·71	12·08	2·33	10·53	2·18	1·0	1·5
						16·48	14·00	10·00		12·67	9·63		7·10		

[1] Percy, "Metallurgy," 1861, p. 211. [2] *L. c.*, p. 213. [3] *L. c.*, p. 214. [4] Maw, vol. xxiii. Q. J. G. S., p. 390.

Moreover, the variations in chemical composition which result in the elaboration of the different felspars and micas, in granites of certain localities, are precisely analogous to the differences in chemical composition of clays, which result from the mechanical conditions of washing, and transport at the time of deposition. These clays have been experimentally analysed by washing, so as to be separated into several parts, each with a chemical composition of its own. And since the first washing removes all the larger particles of sand, it is obvious that the percentage of silica in a clay is merely an expression of the nearness of a deposit to shore, or indicates slope of sea-bottom, or the presence or absence in the ocean of silicious organisms when the deposit was forming.

Evolution of Igneous Rocks.—Stratified rocks present gradations of chemical composition, which commencing with analogues of the most extremely acidic portion of the igneous rocks, gradate into others which represent the extremes of the basic series. And if these sediments were successively melted up and cooled, we should expect the sequence to begin with quartz rock in which but few accidental minerals are scattered, and pass down through an intermediate series into crystalline limestones, in which earthy minerals are rare. The great central part of the group has the chemical composition which is required to produce all the known types of igneous rocks, if it were open to the influx of sea-water. And the local conditions of more or less perfect separation of the mechanical substances, and products of the growth and decay of various groups of vegetable and animal organisms, may explain the fact that almost every locality has its local varieties of the rock families, to which its igneous rocks belong. In nature a perfect geographical gradation of altered sediments can never be expected, because it could only occur along an existing coastline, which was at right angles to some ancient shore-line, which furnished sediments in horizontal sequence; and then we should require these sediments to have been melted up along their extent, without mixture with other deposits. The vast thickness of ancient clays, as exemplified in the older primary strata, may account in part for the absence of liquefied silicious rocks; but the greater fusibility and capacity of the felspathic sediments for aqueo-igneous changes, would influence the extrusion of rocks of this character, to the exclusion of the extreme terms of the horizontal series of aqueous rocks deposited. Geological sections show, however, that strata of different mineral character are superimposed on each other. If, then, such sediments are inferred to become so folded, compressed, and heated by internal contraction of the earth's crust as to be melted up in succession, according to the order in which they rest upon each other, and to become partially mixed in the process of eruption, there ceases to be any difficulty on chemical grounds in accounting for either the normal trachytic or normal pyroxenic groups of Bunsen, or for any of the intermediate or extreme types of eruptive rocks succeeding each other from the same eruptive throat. And when the chemical compositions of the several groups of volcanic rocks are

compared, there are no such differences between them as would suggest difficulties, on that account, in recognising their homologues among stratified deposits. This hypothesis shows how the microscopic crystalline texture may help to unfold the evolution of lava, and yet how subordinate from a physical point of view are the refinements of such analysis, since they manifest what may be termed mechanical accidents which have governed the development of certain minerals in natural association in igneous rocks.

Clarence King's Views on American Volcanic Rocks.—Mr. Clarence King conceives the volcanic rocks to belong to an altogether different type from the plutonic rocks, and to have originated in different ways. He bases his distinction upon the occurrence of glass inclusions in the crystals of lavas, and fluid inclusions in the crystals of plutonic rocks. To us this difference is chiefly indicative of the different conditions of pressure under which the rocks respectively cooled, which allowed the water of volcanic rocks to escape. It is, moreover, by no means a universal law, and the fact that one whole class of volcanic rocks, the propylites, is characterised by fluid inclusions in the quartz, prevents us from attaching fundamental importance to this condition. And in consequence of this circumstance, Mr. Clarence King, who finds no difficulty in accepting the metamorphic origin of granites, does not see his way to accept the metamorphic origin of lavas. Further, he finds each of the types of lava, in the far west of the United States, to present such mineral differences that each may, as a rule, be said to present three modifications, characterised respectively by quartz, hornblende, and augite, as in the following scheme:—

Clarence King's Classification of Tertiary Volcanic Rocks of America.

Propylite . .	Quartz-Propylite. Hornblende-Propylite (rarely micaceous). Augite-Propylite.
Andesite . .	Quartz-Andesite (or Dacite). Hornblende-Andesite (rarely micaceous). Augite-Andesite.
Trachyte . .	Quartz-Trachyte. Mica-Trachyte (rarely hornblendic). Augite-Trachyte.
Neolite . .	Quartz-Rhyolite (or nevadite). Mica-Rhyolite (rarely hornblendic). Basalt.

The propylite and andesite are regarded as of pre-miocene age, the trachyte, and so-called neolite, are classed as post-miocene. Each of these groups is supposed to have been erupted in succession from subterranean lakes in which fusion was produced as a consequence of denudation, which removed the vertical pressure of superincumbent rock, and so enabled the heated mass to become liquid. It is presumed that with successive ages of geological time denudation increased, and fusion extended deeper and deeper. We have failed to discover any evidence of such successive denudations, though the denudation of the great American table-land was beyond doubt enormous; and the

circumstance that these lavas are superimposed on each other in great thickness over broad areas, is some evidence that no denudation adequate to liquefy rock in so grand a scale could have taken place.

It was suggested by Scrope that separation of crystalline substances in the magmas might take place, so that specific gravity would exercise an influence in arranging igneous materials in order of their densities; and Clarence King also takes it to be certain that the crystals in lavas were mostly formed before eruption. Hence, each of these supposed fiery lakes is believed to have been a cauldron in which the light quartzose rock floated towards the surface and was erupted first; and the heavy augitic rock sunk towards the bottom, and was erupted last, so as to account for the threefold type of each rock given in the table. These views seem to rest on the facts observed by Charles Darwin in the Galapagos Islands, that crystals were abundant in the lower part of a lava stream and wanting above, and this circumstance has been observed again by King in the lavas of Kilauea. But although the fractured crystals and fluxion structure of rhyolites prove that the crystals formed before the mass become absolutely solid, the Galapagos and Kilauea observations are more likely to show that the lavas cooled more slowly where in contact with the mountain than when exposed to the air; and, therefore, that the crystals were produced under conditions of slower cooling in harmony with all other observations. And if we were once to admit the formation of crystals in the heated rock and their arrangement according to specific gravity as supposed, it would be difficult to see why the process should not have gone a step further, by separating the minerals themselves, and obliterating the magmas or varieties of the volcanic rocks. The sequence manifested by the American rocks of the Fortieth Parallel certainly needs explanation; but Clarence King's hypothesis, though preferable to Richthofen's, which would derive the lavas from successively lower zones of the earth's interior, leaves much to be desired.

If we compare the varieties of granite with the varieties of any of Clarence King's volcanic rocks, we might easily construct a parallel series, except that the augitic member would be wanting; but the absence of such a rock may not be thought unaccountable when we remember that according to Mitscherlich, Berthier, and G. Rose, the actinolite and grammatite varieties of hornblende, when fused in a porcelain furnace, yield crystals which have the form of augite.[1] And, therefore, the granites, hornblendic granites and syenites, might be held to present the same gradations from acidic to basic types, which are seen in the American groups of volcanic rocks. The other igneous rocks may be similarly arranged.

Relation between Plutonic and Volcanic Rocks.—If lavas are poured out on the surface, we may fairly conclude that parent masses of the same rocks consolidate beneath the surface under different conditions of temperature, pressure, and liquefaction. And if correspondence in chemical composition can be established between certain

[1] "Phillip's Mineralogy," by Brooke and Miller p. 302.

	Analyses of American Sandstones.[1]				
	Between Cottonwood and Unionville Cañons, Triassic.	Cottonwood Cañon.	Near Cottonwood Cañon.	Battle Mountain Carboniferous.	Brown's Hole, Eocene.
Silica	74.74	69.60	85.77	75.32	62.43
Alumina	14.14	17.21	7.60	15.19	14.57
Ferric oxide	0.79	3.66	0.89	3.30	trace
Ferrous oxide	...	...	...	...	...
Lime	1.61	0.74	0.27	...	1.86
Magnesia	0.39	0.71	0.23	2.61	1.41
Potash	5.29	4.50	3.39	0.22	4.90 (Potash and Soda)
Soda	0.92	trace	0.79	0.31	
Water	1.88	3.20	0.70	1.58	14.86

	Analyses of British Sandstones.[2]					
	Cambrian Grit, Barmouth.	Yoredale Sandstone.	Millstone Grit Sandstone.	Coal Measure Sandstone.	Bunter Sandstone.	Neocomian Sandstone, Hunstanton.
Silica	80.60	75.75	87.40	85.55	87.15	49.81
Alumina	9.20	8.22	3.99	7.57	3.94	5.17
Ferric oxide	trace	10.52	...	...	1.35	29.17
Ferrous oxide	2.37	1.35	1.36	1.91	...	0.35
Ferric Persulphate	...	...	0.30	0.75	0.20	...
Carbonic Anhydride	1.02	...	1.87	...	1.20	...
Sulphuric Anhydride	trace	0.17	0.06	trace	0.09	...
Phosphoric Anhydride	0.07	0.15	trace	0.07	trace	0.42
Manganese oxide	0.23	trace	0.27	...	...	...
Lime	1.33	0.53	1.933	0.58	2.68	2.43
Magnesia	1.28	0.36	0.68	0.61	1.08	0.95
Potash	1.64	1.05	0.74	0.91	1.27	0.48
Soda	1.37	1.28	0.33	1.11	0.84	0.84
Water Hygrometric	0.12	0.15	0.05	0.40	0.15	3.85
„ Combined	0.93	0.70	1.29	0.85	0.30	6.56

[1] U. S. Geol. Surv. 40th Parallel, vol. i. p. 542, Table vii.

[2] J. A. Phillips, Q. J. G. S., vol. 37, p. 21.

lavas and plutonic rocks, we are justified in believing that they are connected in origin. This connection is at present best made out in the case of the granites and felsites or altered rhyolites. For, first, there are the experiments of Sir James Hall and others, proving that when granite is melted and cooled slowly it forms a substance like felsite, and when it cools more rapidly the product is a glass like obsidian. And, secondly, there are the descriptions by Professor Judd of the tertiary felsitic rocks of the inner Hebrides, which can be shown to have originated from extinct volcanoes of which the central cores are granites; and the same fact is demonstrated in the primary period, by the occurrence of felsites in Scotland under circumstances which show that they have been derived from granite masses. Therefore the step is sufficiently probable which would lead us to derive felsites and all the imperfectly crystallised or glassy forms of granitic rocks from the metamorphism or melting up of certain clays, and their extrusion or ejection on the earth's surface; but some may have been derived from sandstones.

Igneous Rocks related to Sandstones.—There are no igneous rocks which correspond entirely in chemical composition with the few sandstones which have been examined. Those analysed by Mr. John Arthur Phillips all contain a smaller percentage of alumina than is usual in rhyolites; but rhyolites vary sufficiently among themselves in this respect, as may be seen from the analyses collected by Justus Roth,[1] to justify a comparison. The tertiary rhyolite, described by Mr. Hardman, from Tardree, near Antrim, has, however, but 5·10 per cent. of alumina to 76·96 per cent. of silica. The analyses of American sandstones correspond with rhyolites very closely; the only difference being a slight variation in the proportions of potash and

	Rhyolite of Mont Dore.	Cottonwood Triassic Sandstone.
Silica	74·80	74·74
Alumina	14·47	14·14
Peroxide of iron	1·03	0·79
Manganese	trace	...
Lime	0·43	1·61
Magnesia	...	0·39
Soda[2]	6·63	0·92
Potash	1·69	5·29
	CO^2 trace	...
Water	0·96	1·88

soda. We therefore suggest that rhyolites are often sandstones which have been liquefied and erupted. The way in which the quartz

[1] "Beiträge zur Petrographie der plutonischen Gesteine." 4to. 1873.

[2] In the Rhyolite of Otting, the proportions of the alkalies are reversed, being soda 1·55, potash 5·25.

occurs in grains, in this and certain other volcanic rocks, is probably not entirely unconnected with the occurrence of quartz in separate grains in the rock which was metamorphosed; while, in some cases, we attribute the formation of glass inclusions to the action of heat upon the fluid inclusions in quartz grains, by which the water and alkaline chloride contents have fused the silica with which they were in contact, so as to convert the fluid cavity into a glass "inclusion." If rhyolites are typically the lavas of granites, and do not form a distinct and more highly silicious group, it is because of the diversity of rocks included under the name granite; and just as certain sandstones graduate into certain clays, so certain rhyolites represent some highly acidic granites.

Zirkel's Classification of Igneous Rocks.[1]—Zirkel has always recognised the tertiary lavas as representative in time of the older lavas, and as connected with plutonic rocks. His classification of these rocks, according to the predominant or typical mineral of the felspar family, expresses chemical as well as mineralogical differences between the chief groups, and the affinities which he believes to exist between the older and newer rocks.

I. Orthoclase Rocks.

With Quartz or excess of Silica.	Without Quartz, with Plagioclase.	Without Quartz, with Nepheline or Leucite.
Granite.	Syenite.	Foyaite.
Granite Porphyry.	Augite-Syenite.	Miascite.
Felsite Porphyry.	Quartzless Orthoclase Porphyry.	Orthoclase-Porphyry.
Rhyolite.	Trachyte.	Phonolite.
Obsidian.	Augite-Trachyte.	Leucite rock.
Perlite.		Sanidine rock.
Pumice.		
Pitchstone.		

II. Plagioclase Rocks.

With Hornblende.	With Augite.	With Mica.
Quartz-Diorite.	Diabase.	Mica-Diorite.
Diorite.	Augite-Porphyry.	With Diallage.
Porphyrite.	Melaphyre.	Gabbro.
Hornblende-Porphyrite.	Augite-Andesite.	With Hypersthene.
Quartz-Propylite.	Felspar-Basalt.	Hypersthenite.
Propylite.	Tachylyte.	With Olivine.
Dacite.		Serpentine (Forellenstein).
Hornblende-Andesite.		

III. Nepheline Rocks.

Nephelinite.
Nepheline Basalt.

IV. Leucite Rocks.

Sanidine Leucite Rocks.
Leucite Basalt.

The Basic Series of Volcanic Rocks may be similarly paralleled by analyses of shales, clays, slates, and schists, see p. 225 and p. 285;

[1] U. S. Geol. Explor. Fortieth Parallel, vol. vi. p. 6, 1876; compare also Zirkel, "Lerhbuch der Petrographie," vol. i. p. 450, 1866.

and as closely as rhyolites and granites, though the number of analyses of sedimentary and foliated rocks hitherto made is too few to demonstrate correspondence with all the varieties of igneous rocks which might be selected. This deficiency may be remedied hereafter. But if the views enunciated are sufficiently supported by facts, further details will become available, and repeat the general principles which we have attempted to exemplify.

It remains to be shown that rocks and minerals can be produced artificially.

Experimental Formation of Volcanic Rocks.—Messieurs Fouqué and Lévy by a series of ingenious experiments have succeeded in forming volcanic rocks artificially, not indeed by transforming sedimentary deposits, but by heating together constituent minerals of the rocks. Thus andesite and andesite porphyry are obtained by combining four parts of oligoclase with one part of augite, and heating them together for three days in a platinum crucible half embedded in the furnace. In this process oxide of iron may be produced at the expense of the augite. When a little lime is added microliths of labradorite are formed, and augite forms more abundantly round these than round the oligoclase. In a similar way augite-andesite has been obtained by mixing ten parts of oligoclase and one part of amphibole, when the amphibole is changed into pyroxene. Basalts have been made artificially by a double heating of a black glass, having a composition which corresponds to 6 of olivine, 2 of augite, and 6 of labradorite. This is raised to a white heat, maintained for forty-eight hours, above the melting point of pyroxene and labradorite, when peridote is formed in a brown glass. Subsequently the mass is exposed for forty-eight hours to a red heat, when microliths of labradorite, augite, iron oxide, and picotite are formed.

By combining nepheline and augite in the proportion of 3 to 1·3, nephelinite results after two days' heating; but when the augite is in the proportion of 1 to 10, it gives rise to octohedrons of spinelle and dodecahedrons of melanite garnet. In the same way 9 parts of leucite are combined with 1 part of augite and heated for three days, when crystals of leucite were found to be surrounded by augite and oxide of iron. In this production of leucitite double fusicn is necessary, in consequence of the different fusibility of leucite and pyroxene. The formation of lherzolite is more difficult and less complete. And from negative results, Fouqué and Lévy infer that the rocks containing quartz, orthoclase, black mica, and amphibole, have not been formed by the agency of heat alone. For the methods of artificial formation of the minerals which enter into the composition of igneous rocks, we must refer to "Synthèse des Minéraux et des Roches" by these authors.[1]

[1] The three preceding chapters are the matter of Royal Institution lectures, delivered March 15, 25, and April 1, 1882.

CHAPTER XV.

THE GRANITIC OR PLUTONIC GROUP OF ROCKS.

From a geological point of view it is convenient to associate together all the deep-seated rocks which are completely crystallised, for they occur under similar conditions. The term granitic applied to these rocks, which have a granular texture like granite, merely indicates similar conditions of solidification for the rocks which are associated under that name. From the point of view of evolution it would be more natural to associate the volcanic rocks with their corresponding plutonic representatives. The student in a granitic district will not, however, usually be able to trace the granite into rhyolite, the syenite into trachyte, or diorite into andesite, even if there be some indications of a passage from gabbro into dolerite. Hence, though important questions of theory are involved in establishing the unity of the plutonic and volcanic series, no practical inconvenience will be found in grouping together the massive igneous rocks, which form axes of upheaval, and have been exposed at the surface by denudation.

Mineral Composition of Granite.—The term granite in its modern sense was first used by Werner.[1] As already indicated, this rock is typically a crystalline mixture of orthoclase (and oligoclase), quartz, and mica, varying in texture with the size of the crystals, which are sometimes as fine as mustard-seed, and sometimes as large as the closed fist. When the crystals are large the texture is more irregular. When an uncrystalline matrix separates the crystals from each other, the rock is passing into felsite, a term still conveniently used for altered rhyolitic rocks.

The orthoclase constituent, which usually occurs in twin crystals, cleaves with a pearly fracture and gives granite its characteristic colour, being pink, red, or brownish red, reddish brown, white, yellowish grey, green, or reddish grey, and is even blue in Connecticut and the Pyrenees.

The oligoclase is less transparent, contains more soda than orthoclase, is more fusible, and has a grey or greenish tinge. In some granites, these felspars are in about equal quantity. Frequently in Scotch granites the oligoclase surrounds the orthoclase crystals as a rind. Professor Zirkel points out that at Schreibershau, in the

[1] See Zirkel's "Petrographie," 1866, a general history of plutonic rocks, indispensable to the student, from which we have quoted numerous facts.

Riesengebirge, the orthoclase is flesh-red and the oligoclase snow-white, as in some Scotch granites; and at Viborg, in Finland, the orthoclase is flesh-red and the oligoclase green. Though in such cases the oligoclase is formed subsequently, yet in the granite of Beyrode in the Auvergne, the two minerals alternate in the same crystal, or the oligoclase may have been first formed.

Albite also has been recognised in granite, especially in the Mourne Mountains, and the chemical composition appears to indicate the existence of labradorite and other kinds of felspar in some localities, especially in Ireland, and at Strontian.

Quartz usually occurs in more or less angular grains, but not often with the crystalline faces perfectly developed. It varies in colour like the felspar, being blue in Monte-Rosa and sometimes blue in the Mourne Mountains, and red in the Jägernthal in the Vosges, though commonly colourless. At Gablonz in Bohemia the quartz crystals are larger than the orthoclase.

The mica generally occurs in thin plates which are often hexagonal. Crystals are rare. It varies in colour, being silvery white, brown, or black. The white potash mica is more diffused than the black magnesian mica, which is brown or green in polarised light. Both kinds often occur together. At Penig, in Saxony, the mica is olive-green. Certain large-grained granites contain lithia mica. Haughton recognises the silver-grey mica margarodite in the granite of the south-east of Ireland, and other varieties of the mineral in other localities. As is well known, these minerals are usually mixed together without any trace of a schistose arrangement.

Mica is the most variable element in granite. It is more or less replaced in the Alps and some parts of the Schwarzwald by talc. In the granites of the Pyrenees graphite is associated with mica. Sometimes hornblende is associated with magnesia mica, forming a syenitic granite. Apatite is generally present. Zircon is occasionally found. In porphyritic granite large crystals are only formed by the orthoclase: the well-known Carlsbad twins are among the finest examples of these, sometimes reaching in the Pyrenees a length of six inches. Occasionally the crystals are broken and reunited.

Granite is usually compact, but sometimes porous, and in South America allows water to pass through it so freely as to be used for filters. And it may contain cavities which have the walls covered with crystals of the chief constituent minerals as well as various accessory minerals, as may be seen at Lugano, Baveno, Mourne, and in many localities for European granites.[1]

Chemical Variation in Composition.—The silica in granite varies from 62 to 82 per cent.; the alumina from 7 to 19 per cent.; the iron oxides from less than a quarter per cent. to 6 per cent.; lime from ·13 per cent. to 5·5 per cent. Magnesia may amount to 2 per cent., or show little more than a trace; potash varies from 2 to 7 per cent.,

[1] For a list of the accessory minerals found in the granites of different localities the student should consult Zirkel's "Lehrbuch der Petrographie," vol. i p. 481.

and soda varies from a trace to 6·3 per cent. Water may be absent, and never amounts to more than 2 per cent.

Chemical Classification of Granites.—Haughton proposed in 1856[1] to divide granites into a potash group and a soda group, because the percentage of these alkalies not only determines the kind of felspar in the rock, but usually has a relation to the percentage of silica. Thus in the granite of Croghan Kinshela, in Wexford, the soda amounts to 5·58 as against ·4 of potash, while the silica is 80 per cent. At Baveno the soda amounts to 6·12 and the potash to 3·55 per cent., while the silica is 74·82. When the percentage of potash increases, the amount of silica frequently diminishes, though there is no necessary relation between these substances.

Mineral Varieties of Granite.—The percentage of quartz in granites varies, according to Haughton, from 20·0 to 35·0, though Delesse states it as high as 60·0 in a granite of the Vosges.

The mica varies from 4·0 to 27·0 in Irish granites, while at Tholy, in the Vosges, it is stated to be only one per cent.

The felspar varies from 40·0 to 69·0 in Irish examples, though the highly quartzose granite of the Vosges, already referred to, has but 35·0 per cent.

So great are the variations in mineral composition of granites that it becomes necessary to recognise the value of adventitious minerals in distinguishing local modifications of the rock. Besides the type, the following varieties may be defined:—

Granitite, formed of red orthoclase, much oligoclase, little quartz, and little dark-green magnesian mica. It is especially distinguished by the absence of potash mica, the predominance of oligoclase, and the reduced importance of the quartz. It contains magnetic iron and titanic iron. Many Irish granites are intermediate between the typical granites and granitite. In British geology the rock has no certain representative, and the term is chiefly used in the Riesengebirge, Harz, &c. Augite-bearing granitite occurs in dykes in the metamorphic rocks of Laveline in the Vosges, at Titisee in the Schwarzwald, &c. It is less common than hornblendic granitite. The augite is formed in green prismatic crystals or crystalloids.

Protogine, or talc granite of the Alps, has the same composition as granite, but contains in addition a pale green talc-like mineral. Its quartz is easily broken. The oligoclase has a greenish tinge, while the orthoclase is grey. The mica is usually in six-sided plates. The talc is only freely developed when the rock becomes schistose. It is well seen in Mont Blanc and the Western Alps. Between Schneeberg and Eibenstock, in the Erzgebirge, it contains no mica, and the felspar is flesh-red.

Syenitic Granite or hornblendic granite is intermediate between granite and syenite. It contains less quartz than granite, and hornblende to a large extent takes the place of the mica, which is always dark. It forms the summits and central parts of the Vosges. The accidental minerals are sphene, zircon, chlorite, iron pyrites. In

[1] Quart. Jour. Geol. Soc., vol. xii. p. 177.

Jersey the syenitic granite is red. The red rock at Syene, in Egypt, is a syenitic granite. Characteristic syenitic granite is seen at Strontian, in Argyleshire.

Gneissose Granite is granite which has a schistose character.

Graphic Granite is also schistose, but consists of orthoclase and quartz, so arranged in parallel layers that a transverse fracture exhibits the quartz in forms, suggesting letters of an Oriental language. It occurs near Ilmenau, and by Limoges, &c.

Pegmatite is a kind of giant granite, in which the crystals of orthoclase are sometimes a foot long, and the white mica occurs in large flakes. It is only known in other granite, and generally contains tourmaline, garnet, topaz, &c. It is seen near Penig, in Saxony. Sometimes the greater part of the rock is formed in a milk-white quartz. It occurs in Ireland, according to Zirkel, in Carlingford Bay, and is frequently cavernous, with the walls of the cavities covered with crystals.

Haplite consists almost entirely of orthoclase and quartz, with very little mica. It is seen at Gottleube in Saxony.

Tourmaline Granite is granite in which the mica is partly replaced by schorl. It is seen in Cornwall, and is also known as Luxulianite. The felspar is flesh-coloured, and there is very little quartz.

Beresite is a variety of granite, rich in iron-pyrites, and poor in mica. It occurs in dykes at Beresowsk, in the Ural mountains.

Many other local varieties occur. Thus, in the Fichtelgebirge, at Vordorf, the granite is rich in Epidote, and in Cornwall granite contains tin.

Joints in Granite.—Granite is generally characterised by joints or division planes. In Cornwall they usually run from N.N.W. to S.S.E., or at right angles to the direction in which the granitic masses extend through the country. Near the Land's End, especially off the coast and on the tops of the moors, the granite has a rude columnar structure. In the Harz Mountains there are three principal division planes, one in the direction in which the rock extends, another at right angles to this direction, and a third which is horizontal and less developed. In the province of Constantine, in Algeria, granite is found in regular columns, with five or six sides, which, at a distance, have the aspect of basalt.

In the Riesengebirge and Fichtelgebirge granite often has a spheroidal structure, with the spheres ranging in size from 2 inches to 2 feet. The structure is concentric, and the kernel is sometimes formed of crystals of orthoclase. Near Oporto concretions in granite are 50 feet in diameter.

Decomposition of Granite.—The decomposition of granite is well seen in Cornwall, especially near St. Austell, and at Cornwood, in Devonshire. It is even more marked at St. Yrieix, south of Limoges. Decomposition results from the solvent action of carbonic acid, dissolved in water, acting upon the soda, potash, magnesia, lime, iron, or other soluble constituent of the rock, resulting in the production of a friable rock called *arkose.*

Inclusions in Granite generally have an irregular polyhedral form. They usually belong to the schistose rocks. The larger fragments are sharply angular, but many are rounded, like rolled stones and boulders, some of which, according to Zirkel, have a length and breadth of many thousand feet; one of the largest occurs between Carlsbad and Eibenstock. Sometimes granite veins pass through these inclusions; one such, first instanced by Dr. Forbes, is seen in Whitesand Bay at Land's End.[1] Sometimes the smaller included fragments, which often lie parallel to each other, are so abundant as almost to give the granite the aspect of a breccia. In the Fichtelgebirge, near Reizenstein, the granite is so blended with clay slate as to form a fine brecciated mass, and as a rule the included fragments belong to the neighbouring rocks; and varying with the locality, comprise gneiss, mica schist, clay slate, &c., which have undergone a further metamorphism.

Limestone has been found in granite in the Pyrenees, and can be readily identified with the deposit from which it was derived. These fragments have a crystalline structure, which is better developed on the surface than in the interior; and while the latter retains its dark colour, the surface for the depth of an inch is a snow-white marble.

Zirkel remarks that these inclusions must be carefully distinguished from the small concretions in granite, which usually have a finer texture, and abound in mica.

Concretions in Granite.—Mr. John Arthur Phillips observes that a concretionary patch generally resembles an enclosed pebble, and usually has the outline clearly defined. Such masses, well seen in granite buildings, often enclose crystals of felspar similar to that in the surrounding granite.

In the granite of Lamorna, fine-grained black inclusions are very abundant; they are sometimes traversed by grains of the surrounding granite, and may also contain large crystals of quartz. The felspar is partially orthoclase with a considerable proportion of plagioclase. The orthoclase often encloses grains of quartz and patches of triclinic felspar. The quartz contains the usual fluid cavities; the mica is chiefly dark brown, and often penetrated by well-formed crystals of magnetite. This granite contains light-brown tourmaline and a few small crystals of apatite.

The pebble-like masses when examined under the microscope are found to be a granular mixture of quartz with felspar and an abundance of dark mica; but the plates of mica are mostly parallel. Imperfect garnets are sometimes found in these concretionary patches.

The grey granite of Penryn is almost free from patches of this kind, and they have not been observed in the granites of St. Austell. At Gready, in the parish of Luxulian, the granite contains spheroidal bodies which resemble water-worn pebbles of fine-grained greenstone. These concretions show the black and silvery-white micas, often inter-laminated, but differ chiefly from the granite in a finer grain, and greater abundance of black mica. On analysis the chief difference

[1] "Treatise on Primary Geology," Henry S. Boase, 1834.

is that the concretion contains less silica, more iron, more lime, more soda, and less potash. There are no inclusions or concretions in the Cheese-ring granite near Liskeard. In several localities, as at Foggen Tor, near the Prince's Town prison on Dartmoor, concretionary patches occur in which the outlines are not sharply defined.

Similarly the granite of Westmoreland, at Shap, frequently exhibits rounded patches of a dark colour, in which Mr. Phillips has detected crystals of felspar, partly contained in the concretion and partly in the granite,[1] as may be seen in the St. Pancras Railway Station. These concretions vary in size from a pea to a water-melon, and, like all the others, owe their dark colour to the abundance of mica. They have a ground mass of quartz, felspar, and mica, and contain accidental minerals such as magnetite, titanite, apatite, and hornblende. Occasionally, however, the patches, owing to the absence of black mica, are lighter in colour than the surrounding rock.

In the granite of Aberdeen, the pebble-like concretions are almost unknown. This granite consists of orthoclase, a large proportion of oligoclase, quartz, white and black mica, minute garnets, and occasional crystals of apatite and sphene. The quartz is frequently traversed by hair-like crystals of rutile. Fragments of schistose rocks sometimes occur. Mr. Phillips describes one lenticular mass weighing over a hundredweight found in the Dyce quarry, north-west of Aberdeen. It was covered with a layer of mica so as readily to separate from the rock. On being broken the mass consisted of granite half as fine again in texture as the surrounding rock, and only differed in containing more oligoclase. Near Peterhead, ovoid concretions from the size of a nut to that of an apple are found. They are nearly always dark, fine in texture, and sharply defined. On analysis they contain less silica and less potash, but more iron, lime, and alumina than the surrounding rock. The granite of Ballachulish contains both concretions and fragments of foliated rocks. Many of the Irish granites abound in dark-coloured concretions.[2]

Granite Veins.—The size of granite veins is very variable. They may be fine and interlace like a network. Such are well known in Glen Tilt. At Wicca Pool they often enclose pieces of mica slate. They are numerous in Cornwall. On the Continent they are well seen on the south side of the Brocken in the Harz. Sometimes in such veins the mica disappears, and further on occasionally the felspar also disappears, so as to leave at last nothing but veins of quartz at the termination. These changes are well seen in Arran, in the Valley of the Drummond, and at St. Marie in the Pyrenees. Granite veins three miles long have been described as penetrating the granite near Rossau in Saxony. The texture is often coarse in the middle of a large vein, but it almost invariably becomes fine-grained or felsitic towards the border, showing that the granite was consolidated before the vein penetrated into it. Occasionally, however, the vein may have a coarse texture, while the granite which it penetrates is fine.

[1] Quart. Jour. Geol. Soc., vol. xxxviii. p. 217.
[2] J. A. Phillips, Q. J. G. S., vol. xxxvi. p. 1.

Granite is sometimes supposed to be formed at successive periods in a mountain chain, and in the Thuringerwald, Credner defines three granites having such relations to each other.

Contact Metamorphism.—In the island of Skye, where the granite comes in contact with limestone, the latter rock is changed into a crystalline marble. Many minerals are developed in the limestone near the contact, but the most common are garnet, vesuvian, epidote, spinelle, hornblende, augite, and mica. Clay slate is modified in Cornwall, between Constantine and Penryn, into mica schist and gneissose rock, where it comes into contact with granite, with the development of tourmaline, chiastolite, and other minerals. Similar phenomena are seen in the Pyrenees, Saxony, Brittany, and most of the granitic localities. Hornstone is sometimes produced at the contact by a process of silicification of very fine-grained sandy rocks, though ordinary sandstones become altered into quartzites.

Modes of Occurrence of Granite.—In the south of Russia there is an elliptical granitic area of nearly 4000 square miles. It reaches from Owrucz in Volhynia in a S.E. direction to the neighbourhood of Taganrog, and in a westerly direction stretches nearly to Brody in Galicia. In Saxony, between Gorlitz and the Georgenthal in Bohemia, there is an area of forty square miles of granite. Between the Tagus and Guadiana there is a granite plateau. In those cases the granite is assumed to be horizontal. And many instances are quoted by Zirkel in which granite is an overlying rock, and follows the undulations of slates and schists on which it rests. Among these are the well-known instance on the banks of the Irtish in Siberia, originally described by Von Humboldt; Marhallac's examples in the islands of Milhau in the the Côte du Nord in France; and others in the Harz and the Erzgebirge. But granite more frequently occurs in consecutive masses like chains of islands which have been exposed by denudation, and are elevated with the great folds of the earth's crust.

The principal granitic districts in Europe comprise:—

France.—Eastern part of the Vosges, much of the high land of the Auvergne, the district between Nantes and Parthenay, the Pyrenees, and Brittany.

Germany and Austria.—West of the Schwarzwald, in the Odenwald, south of the Thuringerwald, in the Harz, much of the Fichtelgebirge, several areas in the Erzgeberge, Oberlausitz, in Bohemia, the Riesengebirge, the Sudetic Alps, the highest peaks of the Tatra in the Carpathians, the Böhmerwald.

Switzerland and Italy.—Mount Blanc, St. Gothard, &c., Velteline Alps, Trientine Alps, &c., Corsica and Elba.

Spain.—N.W. province of Galicia, the Sommo-Sierra, the Guadarrama Mountains, the Sierra Morena.

Scandinavia.—A large part of the peninsula.

Russia.—East side of the Ural, and a large area in the south.

Varieties of Granite in the United States.—The granites of North America are classed by Clarence King into eruptive and metamorphic, and he groups the eruptive series into four divisions. The

first type or muscovite granite comprises granites formed of quartz, orthoclase, minute and unimportant crystals of plagioclase, and muscovite, with a small percentage of microscopic apatite. This granite lies to the west of Reese river, long. 117° W. It is seen in Nevada, in the Ravenswood hills, in the Shoshone range, in the Pah-tson mountains, in the Truckee range.

The second type or biotite granite consists of quartz, orthoclase, little or no plagioclase, and biotite, with microscopic apatite. It is seen in the Ombe range, west of Salt Lake, in Nannie's Peak in the Seetoga range, at Mount Tenaho in the Cortez range, on the Wahweah mountains, in the Montezuma range and in the Truckee range, where it is associated with the muscovite granite.

The third type or hornblende granite consists of quartz, orthoclase, little or no plagioclase, biotite and hornblende, with microscopic apatite. Its distribution corresponds very much with that of the biotite granite, with which it is often in close proximity. It is well seen in Granite Cañon in the Cortes range, and at Granite point in the Augusta mountains.

The fourth type or plagioclase granite consists of quartz, plagioclase, orthoclase, and a large percentage of biotite, hornblende, titanite, and apatite. The plagioclase often equals and sometimes exceeds the quantity of orthoclase. Such a granite approximates towards the diorites.[1]

Geological Age of Granite.—The age of granite is always newer than the rock which it penetrates, and older than a stratum deposited upon it. It is rare to be able to fix both of these limits of age. But the more ancient or Silurian granites are found in the Harz, Thuringerwald, Saxon Erzgebirge, Vosges, Christiania in Norway. The granite of Cornwall and Devon is of post-carboniferous date, as also that of Arran. The protogine granite of the Alps is newer than the Lias. And at Predazzo in the Tyrol there are granites of secondary age, and other instances have been quoted near Champoleon in France, of granite overlying and altering secondary limestones. In the Pyrenees both Liassic and Cretaceous limestones are altered by contact with granite. In the Banat the granite is of tertiary age, and similar examples are quoted by Darwin in Chile, and Sawkins in Jamaica.

Syenite.

Syenite is a kind of granite which is typically free from quartz. Orthoclase is the predominant mineral, and is associated with hornblende, biotite, and augite in proportions which vary with the locality. When muscovite appears it is always as a secondary product, due to decomposition of the orthoclase. The minerals in syenite are arranged in the same way as in granite.

The orthoclase in large-grained syenites is often rich in colourless microliths and small plates of specular iron. Sometimes fluid

[1] Clarence King, U. S. Geol. Explor., 40th Parallel, vol. i.

inclusions contain small cubic crystals. The orthoclase twins generally follow the Carlsbad law; they are sometimes white, but commonly red. In many Scandinavian syenites and in the Thuringerwald, the mineral has a blue lustre. Plagioclase, when present, resembles that of granite. In augite-syenite, plagioclase is better preserved than orthoclase.

Hornblende is usually green; when it is brown, as at Laurvig in Norway, the brown colour is deep as in trachytes and andesites. It commonly occurs in lamellar or columnar crystals, and encloses magnetite, apatite, brown mica, and titanite.

The biotite may be green or brown, or both colours occur in the same film. It is associated with the hornblende. The crystals or irregular grains of augite are usually green, but when the rock is very rich in plagioclase, the colour is yellowish brown. Quartz occurs occasionally, and is probably an accessory mineral due to alteration of the orthoclase.

The predominant mineral composition indicates the division of syenite into three types, which may be termed hornblende-syenite, mica-syenite, and augite-syenite.

Geographical Distribution of European Syenites.—Among the European localities for syenite are Plauen, near Dresden, many places on the southern slope of the Thuringerwald, in the Odenwald, Meissen, in Saxony; in Moravia it extends 30 miles from south of Kienitz, through Brunn, to north of Boskowitz; in the mountains of Lower Silesia, a large mass of syenite extends from Glatz to Ullersdorf. A rock of syenitic character, classed by Zirkel as a syenite-granite-porphyry, stretches from north to south in the east of the Banat from Kudernatch to Moldawa. A somewhat similar rock occurs in the Bihargebirge in south-east Hungary, penetrating Neocomian rocks. In the Vosges, massive syenite appears between Windstein and Ballow, north of Geromaguy. In the Tyrol it forms the centre of the eruptive mass at Predazzo, and the great mountain mass of Monzoni, characterised by red orthoclase, white oligoclase, with films of hornblende and brown mica. At Monzoni, the Triassic limestone is converted for a thickness of 100 feet into crystalline limestone, with the development of many accessory minerals. In the South of Norway, syenite is seen around Christiania, penetrating slates and limestones, and in Finland it occurs near Viborg.

North-American Syenite.—There is only one exposure of syenite in the region of the 40th parallel survey. It forms the Cluro Hills in the Cortez Range, Nevada, and consists of flesh-red orthoclase and greenish hornblende. Under the microscope, indications of plagioclase are detected, and there are microscopic grains of quartz, with fluid inclusions.

Hornblende Syenite is generally large-grained, and formed of orthoclase and amphibole, with titanite as an accessory. The type is not so common as is usually supposed, but good examples are seen at Plauen and Leuben in Saxony, and Biella in Piedmont. When the rock is decomposed, calcite and epidote often appear as decomposition

products. And when syenite forms dykes, it contains no titanite and less plagioclase than massive syenite. As in trachytes, of which it is a deep-seated representative, its orthoclase is rich in soda. The varieties of hornblende syenite diverge chiefly towards hornblendic granite and granitite in the Vosges, towards quartz diorite in the Odenwald and Ascheffenburg; while at Laurvig the rock is intermediate between syenite and gabbro, containing olivine, and apparently diallage and hypersthene.

Mica Syenite.—Mica syenite is often termed minette. It usually occurs in dykes. It consists of a fine-grained ground mass of orthoclase, with biotite. The felspar is rarely fresh, it is white or red, and has assumed a microcrystalline texture. Plagioclase is nearly always absent. Though the mica is usually brown, it is sometimes green, or the colours are combined in the same film; the crystals are six-sided. Apatite, magnetite, and pyrites are met with. Calcite and quartz occur as decomposition products. The best types of mica-syenite occur in Calabria, in the Vosges, and Odenwald. At Framont this rock contains green hornblende. At Wackenbach it contains blue glaucophane. In Lower Alsace the minettes contain augite, which is sometimes altered into chlorite or delessite. The minettes of the Southern Schwarzwald are rich in augite. Titanite is usually absent from mica-syenites.

Augite Syenite.—This rock consists of orthoclase, plagioclase, and augite, with some titanite, hornblende, biotite, pyrites, magnetite, and apatite. The two felspars vary in relative quantity. The plagioclase often has a glassy character. The augite is generally green, but occasionally brown, and like the felspar includes the rarer minerals. The green augite often approximates to Uralite, and is sometimes changed to a fibrous chloritic substance. Biotite is generally mixed with augite and hornblende. Titanite only occurs when the rock is massive. Augite syenites occur in the Vosges in dykes. A Uralite syenite occurs in the Ural at Turgojak.

Foyaite, Elæolite Syenite.—Where the continuation of the Sierra Morena enters Portugal it forms the Sierra de Monchique, the north-west of Algarve. This range consists of Devonian slates and sandstones, through which rise the dome-shaped masses of crystalline rocks known as the Foya, 2968 feet high, and the Picota, 2410 feet high. These crystalline rocks cover an area of about 84 square miles. From Foya this rock is named Foyaite; it is a nepheline syenite, in which the naked eye easily distinguishes orthoclase, the elæolite variety of nepheline, and hornblende. Orthoclase is predominant; elæolite shows hexagonal outlines; hornblende occurs in long, slender, greenish-black prisms. The accessory minerals are brownish-yellow titanite, dark lamellar biotite, magnetite, and occasionally pyrite. Under the microscope, nosean and sodalite occur as accessories with triclinic felspar, muscovite, hæmatite, and apatite. The orthoclase is nearly always crystallised with layers of oligoclase. The crystals of elæolite are usually ill-defined. The hornblende and augite are in almost equal quantity, and intergrown with each other. Both are green. The nosean and sodalite

are similarly combined, and both are sometimes embedded in the nepheline. The biotite is brown. When muscovite occurs it is always associated with the felspar and nepheline, and is never combined with the biotite. Titanite is characteristic, and always has a delicate yellow colour. This rock presents a singular chemical correspondence with phonolite, of which it may be regarded as the plutonic representative. Its composition is as follows:—

Analysis of Foyaite.[1]

Silica	56·23	Potassa	5·33
Sesquioxide of iron	·17	Titanic acid	·27
Protoxide of iron	6·21	Phosphoric acid	·13
Alumina	23·15	Sulphuric acid	·09
Lime	2·39	Chlorine	·07
Magnesia	·40	Water	1·06
Soda	3·84		

Zircon-Syenite.—This rock is a granular compound of orthoclase, elæolite, and zircon, with a little hornblende. It is excellently seen in the south of Norway, between the entrance to the Christiania Fjord and Langesand Fjord, stretching north to Skunsfjeld, south of Konigsberg. Another mass occurs north of Christiania, in the island of Seiland in West Finnmark, and at Cape Comfort and Kittiksut in Greenland.

The orthoclase is large and shows a silvery play of colour, which may be blue, green, yellow, or red. There is some difference of opinion as to the identification of the felspar. The elæolite has a greasy aspect; the hornblende is black and rich in soda; quartz is rare, and zircon is found in long columnar crystals. The rock in Maridal contains 66·39 per cent. of silica and 13·79 per cent. of alumina. Fifty accessory minerals have been described from the Norwegian zircon-syenite, and occur chiefly on the margins of the rock as contact minerals, though many are scattered through it.

Miascite.—Miascite is a large-grained granite-like compound of orthoclase, elæolite, and biotite, differing from zircon-syenite in the substitution of black mica for zircon. The felspar is white or grey; the elæolite has the aspect of quartz; and the black mica, in thin plates, is dark green. Sodalite is frequently met with. Hence this rock approaches to some of the nepheline and nosean-bearing phonolites. Octahedral zircon is sometimes present in miascite as an accessory mineral. Ilmenite occurs in crystals some inches in diameter.

This rock is chiefly known from Miask in the Ilmengebirge to the east of the Ural, whence it extends north between granite on the east and gneiss on the west.

A variety which is rich in soda, and contains hornblende and mica, is termed *ditroite*, from Ditro in Transylvania.

[1] Dr. C. P. Sheibner, Q. J. G. S., vol. xxxv. p. 42.

Analyses comparing Syenite with Cambrian Slates.

Syenite.	Stiege in the Harz.	Monte Margola near Pradazzo.	Weidenthal, near Melibocus.	Vetakollen, Norway.
Silica . . .	56·36	58·05	60·97	62·52
Alumina . . .	20·05	17·71	16·44	14·13
Protoxide of iron .	7·96	8·29	10·58	7·38
Manganese oxide .	...	...	0·08	...
Lime . . .	7·22	5·81	5·14	3·36
Magnesia . . .	4·12	2·07	1·80	1·50
Soda . . .	1·70	3·24	0·80	3·05
Potash . . .	2·74	2·98	3·41	6·25
Water and loss .	0·62	1·34	1·03	1·20

Cambrian Slates.[1]	Welsh Slate.	Chiastolite Slate, How Gill.	Skiddaw Slate, Red Pike.
Silica	60·50	65·75	54·48
Alumina	19·70	14·18	20·72
Peroxide of iron . . .	...	trace	0·98
Protoxide of iron . .	7·83	7·30	8·18
Lime	1·12	1·17	1·62
Magnesia	2·20	2·34	1·94
Soda	2·20	1·98	6·21
Potash	3·18	3·26	3·20
Sulphuric acid . . .	...	0·29	...
Loss on ignition and water .	3·30	3·73	2·06

Diorite.

Diorites are essentially combinations of plagioclase and hornblende, but in some localities orthoclase, apatite, and magnetite or titanic iron appear as subordinate constituents; while titanite, magnesia-mica, and pyrites are sometimes present as accessories. The plagioclase was formed first, and occurs in grains or small rods; but when the rock is porphyritic, these crystals are tabular. In the diorites of Guernsey, the Vosges, and many other localities, the twins cross at a right angle, or an angle a degree or two less. Fluid inclusions are rare. The mineral is sometimes so clear as to resemble quartz, but is generally opaque; and when the plagioclase is decomposed, calcite is often developed. The orthoclase in diorite is like the orthoclase of granite. It is chiefly found in quartz-diorite. Hornblende occurs in films or short columns. In the deeper-seated North-German rocks the crystals are broad and large. On the western slope of the Vosges the needle-diorite occurs, in which hornblende forms small slender needles among the rod-like crystals of felspar. Its colour is commonly green, but sometimes brown, as in the quartz diorites of the Odenwald and Vosges. It incloses magnetite, apatite, and sometimes plagioclase and titanite. Where mica is present its crystals penetrate

[1] Clifton Ward, Q. J. G. S., vol. xxxii. pp. 5, 22.

the hornblende, but biotite is often a product of decomposition of the green hornblende. The commonest result of decomposition is a fibrous structure in the hornblende, which is often more or less converted into epidote, though chlorite is the commonest decomposition product. At the Lac d'Aydat it is altered into a substance like serpentine.

When quartz is well developed it always resembles the quartz of granite, and often contains fluid inclusions and microliths; but it is sometimes a secondary product. Augite is only found in diorites with fibrous hornblende; it occurs in clear reddish-brown grains, which are readily converted into chlorite. Garnets occur in diorite near Freiberg and at Aschaffenburg.

Typically the rock often has a true granitic structure; but sometimes, as in the Vosges, Southern Schwarzwald, and parts of Cornwall, it assumes a slaty texture, as though it were a metamorphosed slate. The orbicular diorite of Corsica has a concentric concretionary structure, and is rich in anorthite; an approach to this structure is recorded from Pondières, in the Auvergne, though in the former locality the rock contains augite, and in the latter hornblende. The best-known quartz diorites occur at Quenast in Belgium, and Catanzaro in Calabria. In the latter locality it consists of oligoclase, hornblende, augite, mica, quartz, and chlorite, and has a porphyritic structure. Tonalite may be classed as a quartz-mica diorite. Ophite differs in no respect from ordinary diorite, but a Spanish example contains a true amorphous base, as well as gas and fluid inclusions in the crystals. Rosenbusch regards porphyrites as porphyritic rocks, which would otherwise be classed as mica-diorites. Teall refers the Scotch porphyrites to the andesites.

North-American Diorites.—Among the more typical diorites[1] of the Virginia range is Mount Davidson, 7827 feet high, which is surrounded by the volcanic rock termed propylite. In this diorite the plagioclase is often fresh, and has fluid inclusions. There is no orthoclase, but a good deal of quartz. The hornblende is dark-green, fibrous, and more or less altered, the interstices in it being filled with epidote and calcite. Sometimes quartz occurs in considerable quantity. There are small exhibitions of diorite in Washoe, in basalt cañon, others in the Peavine Mountain in Nevada, and in Truckee cañon, where the rock resembles that of Ilmenau in the Thuringerwald. Some of these diorites are poor in hornblende and biotite, and rich in quartz and apatite. At the Hot-Spring Hills in the Pah-Ute range, the diorite consists almost entirely of plagioclase, with veins and spots of hornblende and magnetite. Many localities in Nevada present slight differences in composition, but there is rarely anything remarkable in its mineral composition, though at the foot of the Augusta Mountains tourmaline appears to be a constituent, and the granular rock of Winnconneca Peak contains dihexaedral quartz, enclosing cubes of salt in the fluid inclusions, like those seen in the Belgian diorite from Quenast, used for paving Paris.

An exceptional variety of dioritic rock occurs as a dyke in granite

[1] Zirkel: Micros. Petrog.

to the N.E. of the Havallah range, where quartz forms a sort of colourless ground mass in which the hornblende is distributed. Larger crystals of quartz and hornblende occur, and there is some brown mica.

Gabbro.

Gabbro consists essentially of plagioclase and diallage. Olivine is rarely an essential constituent. Magnetic iron and titanic iron occur, apatite is abundant; and many gabbros contain hornblende, rhombic pyroxene, brown biotite and quartz as accessories. Gabbros in Guernsey contain hornblende as a chief constituent, but it is probably a decomposition product. Some gabbros approximate to the diabase variety of dolerite. Other gabbros have the plagioclase converted into saussurite, and the diallage more or less replaced by smaragdite.

The plagioclase is either labradorite or anorthite, the latter species being present when olivine occurs. Orthoclase has only been recorded in the gabbros of Monzoni and Val di Susa.

The diallage often fills up the interspaces between the plagioclase; it aggregates round the olivine when olivine is present. At Volpersdorf, diallage and rhombic pyroxene are intimately associated. The pyroxene may be hypersthene, enstatite, or bronzite. This intergrowth of pyroxene parallels the intergrowth of felspars. Parallel interlamination of crystals of diallage or hornblende with plagioclase occurs. The hornblende is sometimes brown, sometimes green, and sometimes results from the decomposition of diallage. The diallage may be nearly colourless, greenish, or brownish. Biotite is the constituent next in importance after diallage; it is abundant in the rock at Waldheim in Saxony and Todtmoos in the Southern Schwarzwald. When enstatite and bronzite occur, they decompose and form bastite.

In olivine gabbros, sometimes olivine, sometimes plagioclase, predominates. When the quantity of felspar is small, the development of serpentine is greatest. Occasionally diallage is absent. The gabbro of Penig is rich in hypersthene, and has little olivine, and so resembles that of Loch Scavaig and the Cuchullin Hills. At Hausdorf the gabbro is free from olivine. A rock of this kind at Harzburg is rich in biotite, and contains augite and quartz.

The silica in gabbro usually varies between 43 and 50 per cent., alumina 13 to 20 per cent., with an average of 10 per cent. of iron, 10 per cent. of lime, and 10 per cent. of magnesia soda and potash.

Geographical Distribution of Gabbro.—In Bohemia, near Ronsberg, the gabbro contains crystals of diallage several inches in diameter, which are surrounded with crystals of hornblende. In the Vosges the gabbro is intrusive, and is sometimes converted into serpentine. In Italy it is seen between Genoa and Savona, and is associated with serpentine in the coasts south of Livorno. In Cornwall it is associated with the serpentine of the Lizard.

Murchison describes hypersthenite in the Stanner Rocks, near Kingston, by Old Radnor, where it is intrusive in Wenlock limestone.

CHAPTER XVI.

HISTORY OF BRITISH PLUTONIC ROCKS.

Age of Igneous Rocks.—When in any country a certain class of rocks, as, for instance, the slate rocks, has been convulsed and thrown into new positions before the deposition of another series upon them, as, for instance, the carboniferous rocks, and we find a mass of granite occupying the axis or nucleus of the dislocation, it is certain that such granite is older than the carboniferous system, because it was uplifted with the older slates. If, in addition, this granite sends veins through the slate rocks so as to prove that it was uplifted in a melted state, we must infer that it is (considered as a solid) of more recent origin than those slates; and, in fact, that the antiquity of its latest fusion is exactly measured by the date of the convulsion.

If there be no veins thrown off from the mass of granite, and no other satisfactory proof of its having been uplifted in a melted state, the age of the igneous rock is indefinable, except by saying that it is older than a given stratified rock. Such a case occurs in the Ord of Caithness. It appears, then, that in any case of convulsion, the era of the elevation of the igneous rock is determined by the convulsion, but whether the rock was actually generated at that time from a melted state requires other evidence. Now this consolidation from a melted state is what fixes the age of an igneous rock. Granite may perhaps have remained in the deep parts of the earth at a melting temperature through many geological periods, but its age as a rock is counted from the period when its fusion ceased.

In Derbyshire the carboniferous limestone is interlaminated for great lengths with a basaltic rock (toadstone), which has evidently been poured out at certain intervals by an ancient submarine volcano while the limestone was in formation. The age of such a rock is fixed by the age of the limestone.

The basalt of dykes which pass through certain strata is, of course, not more ancient than the newest strata divided; if at any point the dyke should be covered by newer strata which are undisturbed by the dislocation accompanying it, we may generally admit that the basalt is older than these strata. Such a case, perhaps, occurs in those dikes of the Durham coal-field, which do not penetrate the magnesian limestone; but it is not always

to be affirmed, because the dikes are there often *unaccompanied by dislocation.*

These instances are sufficient to show the truth of two propositions of general application to this subject.

When igneous rocks accompany convulsions, we can always fix the *minimum* of their geological antiquity; when they throw off veins or intrude in the shape of dykes, or interpolated beds, among stratified rocks, we are able to assign the *maximum* of their antiquity.

Guided by these views, and restricting our illustrations as much as possible to the British Isles, we proceed to describe some details of the characteristic phenomena of plutonic rocks, and to fix the eras of their production.

In referring to the works of authors who have written on granite, we have sometimes followed them in using the terms eruptive granite and metamorphic granite, because these terms conveniently express differences in the relations of granite to the associated rocks; and not as implying that the origin of granite may be different at different points in the same chain; for we have already expressed an opinion that most eruptive granites are only metamorphic granites which have been injected into fissures or otherwise displaced by faulting from the positions in which granitic structure was first developed.

South-West of England.

Granite of Cornwall.—The granite of *Cornwall*, as described by Mr. John Arthur Phillips, F.R.S., is usually coarse-grained, and in addition to quartz, felspar, and mica, almost invariably contains schorl. Sometimes the mica is partly replaced by a talc-like mineral, and the granite thus becomes a kind of protogine. This rock is cited by Dr. Boase[1] as occurring a few miles north of Penzance, but its existence is denied by Dr. Haughton. The mica frequently becomes almost replaced by schorl, and in many places the felspar disappears also. The felspar is orthoclase, sometimes mixed with albite. The black or dark brown mica is either muscovite or lepidomelane, and the pearly white or pink mica is lepidolite. The quartz is usually granular, but sometimes in distinct crystals. It is transparent or white, occasionally bluish or grey, and abounds in microscopic cavities, which may be either partly full or empty.

Mr. Phillips has found that at a temperature of 185° centigrade some of the bubbles in the quartz greatly diminish in size, and infers that they disappear at very varying temperatures; and since many of the cavities appear to be full, it may be concluded that the depth at which the rock consolidated, as inferred by the method of Dr. Sorby, is open to considerable doubt.[2]

Schorl Granite of the West of England.—There are six principal masses of granite in Devon and Cornwall, including the Scilly Isles,

[1] "Treatise on Primary Geology," 1834, p. 20.
[2] Q. J. G. S., vol. xxxi. p. 330, J. A. Phillips.

besides smaller patches at St. Michael's Mount, Tregonning and Godolphin Hills, Carn Brea, Carn Marlts, near Redruth; Cligga Point, near St. Agnes; Castle au Dinas and Belovely Beacon, near St. Columb Major and Roche; Kit Hill and Hingston Down, near Callington; and at Lundy Island.[1]

The range of the granite is 24° N.E. Schorl is chiefly developed in it on the confines of the various masses.

Dartmoor.—The granite of *Dartmoor* is coarse-grained, with the mica sometimes white, sometimes black. It is schorlaceous where it joins the slates. The schorl often occurs in radiating nests, especially to the west of Buckfastleigh, but ordinary granite often passes into schorl rock. After the mica disappears, the felspar vanishes, and the rock at last consists of quartz and schorl. Schorl rock is seen at Holne Lee.

Bodmin Moor.—The granite of the *Brown Willy* district is similar, consists of quartz, felspar, and two micas, is often porphyritic, but not particularly schorlaceous, though schorl enters into its composition near St. Cleer.

St. Austell.—The granite district of *St. Austell* or Hensborough is much more variable, and much richer in schorl than those of either Brown Willy or Dartmoor, and is more decomposed. On the west of this district the mica becomes scarce and often absent, and is replaced by a talcose mineral and schorl. Schorlaceous veins are abundant in the St. Austell granite in the western and central portions. A thick vein of dark mica traverses the granite of St. Dennis Down.

Carn Menelez.—The *Carn Menelez* or Falmouth granite is occasionally porphyritic from the presence of felspar crystals, but the grain is regular at Constantine and Mabe. It is poor in schorl.

Land's End.—At the *Land's End* the granite abounds in schorl, and often passes into schorl rock, as on the west of Penzance, at Leity, near Lelant, and on the east of Trecobben Hill. At Trevalgon, near St. Ives, the schorl rock contains large crystals of felspar. The schorl veins in the granite at Wicca Cove, near Zennor, are often several inches thick. This granite contains much pinite.

Scilly Isles.—The granite of the *Scilly Islands* is a somewhat coarse compound of quartz, felspar, and the two micas. Schorl is rare. It is traversed by veins in which the grain is finer.

De la Beche remarks that schorlaceous veins occur in the granite of Kit Hill, and that the mass of Belovely Beacon graduates into schorl rock on the north. The granite of St. Agnes Beacon is on the north a mottled mass of quartz and felspar, containing large crystals of flesh-coloured felspar and semi-crystallised quartz; on the south the rock becomes more quartzose, and is fine-grained and traversed by small veins and strings of black oxide of tin.

On the coast it is composed of quartz, felspar, and a talcose mineral, with occasional specks of mica, and is often marked by lines of felspar crystals. At Godolphin Hill the rock is a base of felspar

[1] "Report on Cornwall, Devon, and West Somerset, De la Beche," 1839, p. 156.

with white crystals of felspar, and nodules of clear quartz and black mica embedded thickly. Schorl veins are there common.

All these granites decompose so as to develop a tabular structure, which is horizontal, and gives the rock a stratified appearance.

In Hingston Down a hard granite alternates with a decomposed granite so as to give a stratified appearance which coincides with the dip of the adjoining slates.

Alternations of schorl rock and granite give a similar stratified appearance near St. Austell.

At Pardenick Point, and other places near the Land's End, the granite resembles a collection of huge basaltic columns.

The Dartmoor granite is of post-carboniferous age, but it pierced through a district which had previously experienced considerable igneous action. Large veins, like dykes, are seen in the Serpentine at Kynance, and in other places. The veins are generally a compound of felspar and quartz.

	Cornish Granites.[1]				Cornish Elvans.[2]			
	Carn Brea Hill, Redruth.	Botallack.	Chywoon Morvah.	Gready in Luxullian.[3]	Tregoning Hill, Breage.	Pra Sands, Sydney Cove.	Mellanear, Hayle.	Trelissick Creek, Carrick Roads.
Silica	74·69	74·54	70·65	69·64	72·82	72·51	71·46	47·35
Alumina	16·21	14·86	16·16	17·35	15·12	13·31	15·38	20·60
Ferrous Oxide	1·16	0·23	0·52	1·94	trace	3·87	2·27	1·60
Ferric Oxide	...	2·53	1·53	1·04	1·75	trace	0·30	3·10
Lime	0·28	0·29	0·55	1·40	0·52	0·60	0·47	4·72
Magnesia	0·48	...	...	0·21	1·06	1·52	0·22	6·12
Soda	1·18	3·49	0·54	3·51	0·51	0·43	2·79	3·58
Potash	3·64	3·73	8·66	4·08	6·25	6·65	5·51	6·29
Manganese Oxide	0·58	trace	trace	trace	trace	0·62	trace	trace
Lithia	0·10	trace	...	Phosphoric Acid. trace	...	Fluorine. trace	...	Fluorine. trace
Hygrometric	0·34	0·87	0·33	0·13	0·26	0·11	0·43	0·34
Water	...	...	...	...	...	...	...	...
Combined	0·89	trace	0·89	0·59	2·03	0·49	1·27	6·11

Elvans.—The term *Elvans* is applied to long lines of granitic and felspar porphyry rocks which cut the slates and granites, and therefore being newer are conveniently distinguished from the granite veins which they occasionally resemble.

The elvans have almost the same chemical and mineralogical composition as the granites, though their ingredients are differently aggre-

[1] J. A. Phillips, Q. J. G. S., vol. xxxi. p. 330. [2] Ibid.
[3] Ibid., vol. xxxvi. p. 8.

gated. The quartz, instead of forming a kind of crystalline residue as in granite, is usually enclosed with the crystallised felspar in a felspathic or quartzose-felspathic base. Mica, schorl, chlorite, and pinite are sometimes accessory minerals; the quartz is often in double hexagonal pyramids with the angles removed and rounded. The felspar is usually in large well-defined crystals, though sometimes so minute as only to be seen with the lens. When the elvan occurs in granite, its texture is generally finer than when it cuts through slate. It rarely penetrates between the cleavage planes of slate. In the principal mining districts the elvans are parallel to most of the productive tin and copper lodes, running a few degrees north of east, though in other parts of the country the elvans run nearly north and south, and almost coincide in direction with the cross courses which often yield ores of lead and iron. Under the microscope the quartz is seen to contain hair-like crystals of schorl.[1]

Distribution of Elvans.—The elvan dykes of Cornwall vary from a breadth of a few feet up to 300 or 400 feet; they are parallel to each other, and can be traced for several miles. One of the longest runs from Wheal Darlington, near Marazion, for twelve miles by Wheal Fortune, Corbus, Treganhorn, Cayle, Roseworthy, and Camborne to Pool, sending off a branch near Cayle about five miles long, which passes by Carnbrae Green, Cassawson, and Tregear into the Carnbrea granite on the west of Camborne Beacon. Another runs along Penzance Pier. Only one has been observed in the Scilly Isles, on the northern part of St. Mary's, running 25° N.W. It has a grey felspatho-quartzose base, containing crystals of light-coloured felspar and quartz. At the Land's End elvans sometimes contain schorl; in the central part of the dyke they are often granitic in texture. The elvan which runs through St. Hilary abounds in crystals of pinite. Elvans are numerous between Redruth and Gwennap, and seem to cut into the granite. The elvan on the west of Killaganoon is so decomposed as to be worked for crucible clays, but they are usually hard. The colour of the rock sometimes changes in a short distance from a rose tint to greenish, and the texture from porphyritic to arenaceous. The Cubert elvan in the centre is a compound of quartz-felspar and mica, though the mica is rare. The upper part of the elvan of Watergate Bay appears to have a concretionary structure. North of the Hensborough granite the elvans are very variable in colour. A group of elvans near St. Austell runs 20° N.E. They sometimes contain nests of sulphide of copper, and occasionally small nests of plumbago. The Pentnau elvan contains fragments of slate rocks, especially in the branch from it which runs along the shore to the Black's Head. Elvans also occur round Brown Willy. The elvan called Roborough stone, on Morwell Downs, abounds in crystals of quartz formed of hexagonal pyramids base to base. Elvans are much divided by joints like the granite. Elvans everywhere have the appearance of having been produced towards the close of the eruption or upheaval of the granite masses near which they occur.

[1] Q. J. G. S., J. A. Phillips, vol. xxxi. p 334.

Charnwood Forest.

The igneous rocks of Charnwood Forest in Leicestershire [1] are chiefly syenite, granite, and diorite.

Syenite.—The syenites occur in isolated masses in the neighbourhood of Groby, extending north-west from that place, where they are surrounded by trias. At Cliff Hill the syenite forms a conspicuous rugged ridge, and another mass is seen at Stanton Field; another occurs at Hammer Cliff. All these exposures are termed by Professor Bonney and Mr. Hill the southern syenites. At Groby the rock is rather coarsely crystalline, and contains dark-green hornblende, with pink and greenish felspar, with small masses of yellowish-green epidote, and occasional grains of pyrites. When the rock is more finely crystalline it is generally of a red colour. The rock is also quarried at Markfield on Cliff Hill. It is generally traversed by bold joints, which usually have a brown ferruginous coating. Under the microscope the rock consists of orthoclase and plagioclase felspar, often a good deal decomposed, and sometimes stained green, with inter-crystallised quartz. The hornblende is often somewhat decomposed so as to appear fibrous, and it is frequently replaced by the mineral epidote, and viridite. The quartz rarely occurs in grains such as are seen in granite. Apatite is found in long clear six-sided prisms. The more compact syenite consists chiefly of inter-crystallised felspar and quartz, the felspar being sometimes replaced by a zeolite. The quantity of hornblende is small.

The rocks termed the northern syenites by Messrs. Hill and Bonney are seen at Bawdon Castle, and to the north-west. A patch also occurs at Great Buck Hill. At first sight the aspect of the rock is different from that of the southern district, being less coarsely crystalline and more altered, passing occasionally into a dull green compact rock. The circumstance that these rocks are rather more basic than the others is associated with the view that they were probably less deep-seated in their origin. Under the microscope the rock appears to contain less quartz. The hornblende is almost entirely replaced by products of its decomposition, such as viridite, chlorite, and epidote. The iron is chiefly in the form of ilmenite. In so far as these rocks differ from the typical syenites they make an approach towards the diorites.

Mount Sorel Granite.—On the left bank of the Valley of the Soar is a mass of rock, forming the height called Buddon Hill and terminating at the village of Mount Sorel. Various outlying neighbouring patches occur on the north-east and south-west, which are all probably connected beneath the trias, so that the granite hills rise from the surrounding strata as from a sea. The colour is usually pinkish, but in the Mount Sorel pit it is sometimes grey. The rock is occasionally slightly porphyritic, and consists of quartz, felspar, black mica, and

[1] Rev. E. Hill, M.A., and Professor Bonney, F.R.S., Quarterly Journal Geological Society, vol. xxxiv. p. 211.

dark-green hornblende, occasionally with pyrites and epidote. Occasionally felsite veins occur in the rock, which is divided up by three or four systems of joints. Under the microscope the quartz and felspar are occasionally inter-crystallised, as in the syenite.

The felspar is chiefly orthoclase, but is mixed with oligoclase. It is inferred by Professor Bonney and Mr. Hill that all these rocks of Charnwood Forest were intruded at about the close of the Silurian period, and are of the same age as the granites and syenites of the Lake country.

Diorite.—To the north of Brazil Wood is a knoll of dark diorite which consists of white plagioclase felspar and hornblende.

Anglesea.

Granite of Anglesea.—The reputed granite of Anglesea furnishes a notable instance of the way in which the nomenclature of rocks sometimes changes, with a new interpretation, for most recent writers deny that the island contains any granite at all.

According to Sir Andrew Ramsay the granite runs across the island in a broad irregular belt nearly 12 miles long. Its greatest width is less than 3 miles. Where best developed it is composed of quartz, felspar, and black and silvery mica, but it is usually coarse, with the felspar not well crystallised, and the mica often absent. It is regarded by Dr. Hicks as a Dimetian rock. All along the south side towards Caernarvon Bay, it is bordered by a belt of hard felspatho-silicious-looking rock, sometimes faintly laminated or more clearly foliated. This band Dr. Hicks names Hälleflinta, and identifies as Pebidian. Near Bodwrog portions of foliated rocks are interlaced with the granite, and further west there is a mass of altered rocks entirely surrounded by granite. The foliated semi-crystalline rock often almost melts into the granite. Elsewhere it passes insensibly into foliated hornblendic gneiss. On the west the boundary between the granite and gneiss rocks is equally obscure. In some places innumerable granite veins ramify into the gneiss, and so alter it that the two rocks are inseparable. Round Handrygarn much of the granite is hornblendic. Professor Ramsay remarks that it was impossible not to be impressed with the idea that the granite and its veins are merely the result of a more thorough metamorphism than was attained in the production of the associated gneiss. And he observes that the stratified rocks near to its margin dip indifferently towards it and from it, as if part of the strata had been used up in the making of the granite itself. In the west of the island, near Llan-Trefwll, there is a small patch of granite, round which the Cambrian rocks are much altered, and several small hornblendic patches, which were formerly regarded as greenstones. West of Treath Dwlas a larger granitic mass stretches two miles inland.[1]

[1] Ramsay, North Wales. These rocks have since been described by Dr. Hicks, Quarterly Journal Geological Society, vol. xxxv. p. 295, as Precambrian. Professor Bonney terms the rock Granitoid gneiss, and gneiss. Dr. Callaway (Q. J. G. S., vol. xxxvii. p. 210) names much of the rock Granitoidite.

Granitic Rocks of the Lake District.

The igneous rocks of the Lake District were well described by the late Mr. Clifton Ward.[1]

The Skiddaw Granite occurs in small inlying masses, the largest being only a mile long and half a mile wide. It is seen in the valley of the Caldew, and in the course of Sinen Gill, and is everywhere surrounded by Skiddaw slates, which are greatly metamorphosed by the contact. There is no evidence that these granite masses were the cores of old volcanoes, since the volcanic rocks which occur in the surrounding strata are more basic and chiefly belong to the basaltic family.

The felspar is partly orthoclase and partly triclinic, the latter showing the usual coloured bands when seen under polarised light in microscopic sections.

The quartz contains many fluid cavities with moving bubbles and hair-like crystals, as well as others which are stout and long. The mica is mostly dark-brown. There are a few grains of magnetite. Mr. Ward infers that the Skiddaw granite has never been covered by a greater thickness of strata than 38,000 feet.

The liquid cavities in the quartz are considered to indicate a pressure equal to 52,000 feet of superincumbent rock, it being supposed that this pressure was exerted in the upheaval of the overlying rocks, and that the Skiddaw granite consolidated at a temperature of about 680° Fah.

The Eskdale Granite is only met with surrounded by the volcanic series of Borrowdale. From the thickness of these strata it is concluded that not more than 22,000 feet of rock could ever have covered the granite. The granite metamorphoses the rocks with which it is in contact. The pressure which is indicated by the condition of the crystals is stated by Mr. Ward at 42,000 feet. Dykes of quartz-felsite or elvanite from this rock indicate a pressure of 53,000 feet.

The Wastdale Granite is another mass, coloured reddish by its felspar, which is partly orthoclase and partly triclinic, and contains dark-brown mica. An analysis shows it to contain, as compared with the Skiddaw granite, rather less silica and more alumina, less potash and more soda and more iron.

The Wastdale granite is assumed to be in connection with the Eskdale granite. At Wastdale Head numerous veins run into the overlying volcanic series.

The Shap Granite, so well known on Wastdale Crag and Wastdale Pike, is characterised by large flesh-coloured or reddish-brown crystals of felspar. Like the other masses, it is incapable of being connected with any volcanic outburst. The geological evidence indicates that it could not have consolidated under a greater pressure than about 14,000 feet of superincumbent strata, but the calculated pressure indicated by the microscopic structure is 46,000 feet, at a temperature of 502° Fah. This granite is inferred to have cooled very slowly. The metamorphism in the surrounding rocks is less intense than in

[1] Quarterly Journal Geological Society, vol. xxi. p. 568; vol. xxxii. p. 1; Memoirs of the Geological Survey: Northern Part of the English Lake District, 1876.

the Eskdale district. Patches of fine-grained micaceous granite sometimes occur in the middle of the Shap mass.

The Ennerdale and Buttermere Syenite and Syenitic Granite.—The Ennerdale rock is for the most part red and of coarse grain. Usually hornblende is absent or in small quantity, but it is sometimes so abundant as to give with the mica a dark and grey tinge to the rock; and then its texture is fine-grained. It is well seen over the summit of Red Pike. The quartz appears to occupy the interstices between the other minerals, and is not crystallised. Magnetite is sometimes plentiful. Where the syenite meets the overlying volcanic ash it becomes a hornblendic felsite. It has a distinct aspect from the Eskdale granite, though it adjoins that rock at the foot of Wastwater. It extends north and south for about nine miles, and forms in part a boundary between the Skiddaw slates and the volcanic series. The liquid cavities in the quartz indicate a pressure at consolidation equal to 35,000 feet of rock. This mass may have furnished the ashes in the uppermost part of the volcanic series.

St. John's Quartz Felsite.—This rhyolitic rock varies in colour from red to white, and consists of a felspathic base containing crystals of felspar and quartz, with a little magnesia, mica, and some altered hornblende. The felspar is chiefly orthoclase. Grains of magnetite occur. The quartz contains fluid cavities which indicate a pressure equal to 40,000 feet of rock. The masses in which it occurs are rarely more than a mile long. The crystals of quartz in this rock are generally double pyramids, the intermediate prism not being developed. This formation of complete crystals is difficult to reconcile with the theoretical estimate of pressure.

The Armboth and Helvellyn Dyke.—This rock also consists of quartz felsite or rhyolite, and is traced towards the St. John's rock. The dyke, which is 20 to 30 feet wide, is a red felspathic base, with crystals of pink felspar and quartz, with green mica and a steatitic mineral. Most of the quartz is crystallised, but some is interstitial. The percentage of silica is less than in any of the other rocks. The pressure indicated by this rock corresponds to 46,000 feet, it being in accordance with other observations that the pressure is greater in a dyke than in the mass from which it proceeds.

Quartz Felsite of Fairy Crag.—This is a similar area to that of St. John's Vale, and occurs among the Skiddaw slates. It indicates pressure of 49,000 feet. These rhyolitic rocks may be regarded as granitic materials which have not perfectly crystallised. Mr. Ward has noticed that as the rocks severally approach towards the granite masses, especially that of Eskdale, they undergo a regular modification by metamorphism. First, at a distance of several miles, the rock, which may have been a bed of volcanic ash, shows under the microscope hazy and indistinct outlines of the fragments, and frequently a kind of streaky-flowing structure round the larger particles, though remains of original lines of bedding are observable. Nearer to the granite the altered rocks put on a purple tint and develop specks of mica, which are sometimes gathered into nests as the granite

is approached, while finally many small crystals of felspar, and occasionally quartz, become developed in the purple micaceous base.

There are a few felstone dykes in the Lake District. One extends from White Pike and crosses part of Matterdale Common. It is thought to be connected with the St. John's quartz felsite. Narrow dykes of banded felstone occur in the south-west of Buttermere.

Basic Rocks of the Lake District.

Minette.[1]—Professor Bonney describes minettes between Windermere and Sedbergh, running east and west in dykes a foot or two wide, typically seen at Cross Haw Beck. The rock is called minette-felsite at Backside Beck, Helm Gill, south of Haygarth, &c.; mica-diorite at Stile-End Farm; and kersantite at Holbeck Gill. The dykes are probably of Old Red Sandstone age. The Sale Fell rock, according to Mr. Ward, is a pink felspathic base, consisting of orthoclase and triclinic felspar, generally crystalline. It contains dark green mica, probably biotite, and the quartz, which is interstitial, contains many cavities.

Diorites of the Lakes.—Many small intrusive bosses and dykes of diorite burst through the Skiddaw slates and volcanic series of Borrowdale. Several occur on the hill-side north of the railway, between Cockermouth and the Bassenthwaite lake. They are generally fine-grained, with white felspar and dark hornblende and specks of iron pyrites. Quartz occurs, with liquid cavities and moving bubbles. Another quartz diorite occurs on the summit and side of Hind Scarth. It contains a good deal of quartz, with many needle-like crystals. Other masses are found at Burtness Comb. The hornblende is a good deal altered, and glass cavities as well as liquid cavities occur in the quartz. A mass of diorite with picrite is seen at Little Knott on the east of Bassenthwaite lake. It is almost entirely formed of hornblende, the quantity of felspar being very small.

Dolorites or Diorites.—Mr. Ward mentions four principal exhibitions of dolorite, first at Wythop Fells, a fine-grained dark-green rock, with chlorite replacing much of the plagioclastic felspar. Unlike other diorites, this contains many spaces filled with quartz, which contains many cavities with bubbles. A small mass occurs at Castlehead, Keswick. It is a mixture of pale felspar with augite and a soft dark-green mineral. Most of the augite is replaced by pseudomorphs. Another mass is found at Swirral Edge, Helvellyn. It also has the augite greatly altered and converted into a soft green substance. Across the upper part of Longstrath Valley, Borrowdale, run several dykes, which contain felspar crystals embedded in a felspathic base, and mixed with a soft green chloritic mineral.

We hesitate to group any of these rocks as dolorites, and are inclined from the quartz they contain to regard them as perhaps related to quartz diorites. They may perhaps be connected with the Ennerdale syenite.

[1] Bonney and Houghton, Q. J. G. S., vol. xxxv. p. 165.

	Lake Rocks.[1]				Scotch Granites.			
	Eskdale.[2]							
	Granite S. of Great How.	Granite of White Gill, Skiddaw.	Sye·itic Granite of Buttermere.	Quartz Felsite of St. Johns.	Peterhead.[3]	Ross of Mull.[4]	Bell's Grove, Strontian.[5]	Creetown[6]
Silica	73·57	75·22	71·44	67·18	73·70	74·48	62·09	67·04
Alumina	13·75	11·14	15·34	16·65	14·44	16·20	17·60	17·20
Ferrous Oxide	2·10	1·77	1·10	2·15	1·49	...	0·74	0·41
Ferric Oxide	0·61	trace	1·23	0·55	0·43	0·20	4·78	3·15
Lime	1·06	1·62	1·06	2·35	1·08	0·13	4·95	2·92
Magnesia	0·39	1·08	0·72	1·54	trace	0·27	3·17	1·20
Soda	4·31	3·99	3·95	4·03	4·21	3·78	4·08	3·25
Potash	3·51	4·51	4·43	2·91	4·43	4·56	3·25	3·90
Manganese Oxide	...	...	...	...	trace	...	0·40	...
Phosphoric Acid	0·01	0·14	0·11	0·17	trace	...	...	...
Hygrometric Water	...	...	...	...	0·21	...	...	...
Water	...	...	...	...	...	0·60	...	...
Combined Water	...	...	...	...	0·40	...	...	...
Loss	0·66	0·50	0·58	1·54	...	...	...	...

Granite in Scotland.

The granite masses of Scotland are chiefly developed along the course of the Grampian chain, about Peterhead, west of Aberdeen, on both sides of the Dee extending almost to Braemar; one large mass includes Ben Mac Dhui and Cairngorm, another includes Lochnagar. A smaller mass occurs in Glen Tilt, another mass around Loch Luydan, east of Glencoe, and about Loch Etive, a considerable mass includes Ben Cruachan. The base of Ben Nevis is of granite, and there is a remarkable mass of granite at Strontian around the head of Loch Sunart. Granite occurs in the Ross of Mull, and in the central part of that island. Many smaller masses are found in the north of Scotland, as at Strathie Point, and between Strath Ullie and Strath Halladale; and in the south of Scotland in Arran, south of Loch Doon, in the upper course of the Dee, and in the well-known mass of Criffel in Kirkcudbrightshire.

Granite of Banff.—The granite of Banff came into existence after the formation of the old metamorphic rocks. It sends veins into them in the lower Craigellachie district. Mr. Jamieson,[7] however, regards the granite as a metamorphic rock formed partly out of the argillaceous and arenaceous beds, and the greenstone of the Portsoy

[1] Ward, Q. J. G. S., vol. xxxii. p. 1.
[2] Ibid., vol. xxxi. p. 597.
[3] Phillips, vol. xxxvi. p. 13.
[4] Haughton. J. R. G. S. I., vol. i. p. 30.
[5] Scott, vol. i. p. 265.
[6] Haughton, R. Ir. Acad., xxiii.; p 607.
[7] Q. J. G. S., vol. xxvii. p. 105. J. E. Jamieson, on the Granite of Banff.

district. Granitic structure alternates with gneiss structure in the southern part of Ben Aigan. In the hill called Little Conval, near Dufftown, the S.E. base is a large-grained rock with red felspar and little mica, but higher up it becomes finer-grained, and at the top is a mixture of small-grained red felspar and quartz. But the felspar is redder than is usual in gneiss, and the quartz is less in amount.

Grampians.—Of the Grampian chain, Professor Judd remarks that where the lower portions of the masses are exposed by extensive denudation, the rock presents the character of a typical granite, such as is well seen in the Ross of Mull; but where it rises into lofty peaks it becomes more and more hornblendic, and then graduates into felsite, which rock is commonly more or less porphyritic. And it is worthy of notice that a similar series of changes in the character of the rock is often to be observed when the granite is traced from its central portion towards the outer margin. At the junction of the granite and stratified rocks numerous veins, which often include angular fragments of the strata, penetrate the water-formed deposits, and large masses of stratified rocks, altered on their surface, and penetrated by granite veins, are found enveloped in the igneous mass, so that the granite is entangled with the strata. Granite and felstone dykes are well seen in the Passes of Glencoe and Brander, and are always numerous near the central igneous masses.

The central mass of Ben Nevis consists of hornblendic granite, passing by insensible gradations into ordinary granite on the one hand and syenite granite on the other. The period at which these granitic protrusions took place was posterior to the deposition of the Cambrian rocks, which were already metamorphosed when the granite penetrated them; and since this granite never penetrates either the secondary or tertiary strata, it is inferred to belong to the newer palæozoic period. Professor Haughton describes the granite of the Ross of Mull as coarse-grained, with abundance of quartz, pink orthoclase, and a little black mica. It contains 74 per cent. of silica and 16 per cent. of alumina.

The Granite of Loch Etive is described by Mr. R. H. Scott, F.R.S., as consisting of a fine-grained rock in which the felspar is mainly anorthic. It sometimes contains sphene, and includes many fragments of slaty rocks, which are often angular and but little altered; it is traversed by dykes of red quartz felstone, and has all the characters of an elvan. The neighbouring granite is grey, and consists of anorthic felspar, quartz, and black mica. Granite extends on Loch Leven for two and a half miles, and has an elvan character where quarried at Ardshiel and close to the pier at Ballachulish. It is succeeded in the usual way by gneiss, mica slate, and roofing slate. The gneiss of Loch Linnhe often assumes a granitoid character. Up Glen Tarbert, to within four miles of Strontian village, it is absolutely bare of vegetation, and yet shows no sign of chemical disintegration.

The Granite of Strontian extends eight miles east and west; it is dark and coarse-grained, with red orthoclase, white felspar, quartz, a large proportion of black mica and hornblende, with crystals of sphene,

and perhaps zircon. Lenticular masses or nests of black mica occur, in which are crystals of white felspar, quartz, and sphene. On the south shore of Loch Sunart the Strontian granite is more micaceous and hornblendic, and contains large masses of hornblende rock.

Galloway Granite.—Mr. Irvine remarks of the mass of granite called Cairns More of Fleet, which is one of the three large granitic bosses of Galloway, that its colour is grey, shading in places to pink, and its texture coarse, so that on the top of the hill crystals of quartz and felspar are two inches long. The granite usually consists of quartz, orthoclase, plagioclase, and black and white mica; but sometimes the mica may be almost replaced by hornblende, and frequently the quantity of quartz is small. The black mica, called Lepidomelane, is the most common, but in Cranmer, Craiglowrie, and Craigherron Hills a white mica occurs, probably Margarodite. Quartz frequently occurs in hexagonal prisms. No mass of fine-grained granite occurs in the area, but dykes and veins of elvanite are found all through the heart of the granite, and in the surrounding metamorphosed area. The rock consists of white orthoclase felspar, with a little mica, iron pyrites, and quartz. Occasionally, at the circumference of the granite, the rock passes into a compact felstone, with some crystals of hornblende. Many patches of altered stratified rocks are caught up in the granite; the largest, in Blair Buie's Hill, is 600 feet long by 150 feet broad.[1]

The Granite of Loch Ken[2] consists of pink and white orthoclase and plagioclase felspar, quartz, mica, some hornblende, and a little iron pyrites. But the quartz may disappear entirely, and hornblende often replaces the mica. Crystals of sphene abound near Loch Aberloch. Near the margin the rock is foliated, and then hornblende is most abundant. Veins abound on Bennan Hill west of Loch Ken. Near the margin of the granite, felstone dykes are frequent.

Arran.

General Features.—The Island of Arran has been very often described by eminent geologists. Jameson, MacCulloch, Necker, Murchison and Sedgwick, Oeynhausen, Von Dechen, and Ramsay have all written ably on the inexhaustible subject of this little world of geological phenomena. The leading features of Arran are its mountainous and truly Alpine scenery in the northern extremity, and the elevated plateaux of its southern portion. These latter are generally partly of syenite, partly porphyry, partly basalt, with many basaltic dykes and dykes of pitchstone passing through the red sandstone strata.

Granite occupies the central district of the northern half of the Island of Arran, and is especially seen in the mountains. It is surrounded by clayslate, and schistose rocks. Sir Andrew Ramsay

[1] Mem. Geol. Surv. Scot., Sheet 4, 1878, p. 18.
[2] Ibid., John Horne in Explanation Sheet 9, 1877.

remarks[1] that the granite of Goat Fell and the principal mountains is a large-grained variety, in which felspar predominates and mica is comparatively rare. Some of the felspar is light-brown, other crystals are pure white, and a third is glassy, so as to resemble quartz. The quartz too is very variable, being white, pale yellow, grey, light or dark brown, and sometimes almost black. This mineral frequently occurs in hexagonal prisms in cavities in the rock. There are large areas in the interior between Ben Ghnuis and Ben Mhorroinn which consist of a fine-grained granite, and in some of the veins the texture is so fine that the rock might be mistaken in hand-specimens for a sandstone.

In veins the quartz and mica sometimes disappear, leaving the rock in the form of a compact felspar. The mica is in very small black scales. Frequently the granite rises in perpendicular cliffs

Fig. 54.—From the top of Goat Fell (Arran).

which are well seen on Goat Fell, the west side of Ben Ghnuis, and on the peak of Caisteal Abhael. The junction of the granite and slate is seen in Glen Rosa and Glen Sannox, the slate being penetrated by veins. A mass of fine-grained granite forming part of the hills which surround Glen. Dubh at the upper part of Glen Cloy, contains a large proportion of reddish felspar. It is partly surrounded by syenite and porphyry, and the syenite has metamorphosed the sandstone into quartz rock.

Alterations of Stratified Rocks in Arran.—No new minerals are produced in the slate where the granite touches it, nor in the red sandstones where they are hardened by the basaltic dykes. This hardening is very various in degree, and the causes of these differences are not very evident even upon the examination of many cases. The

[1] "Geology of the Isle of Arran from Original Survey," 1841.

hardening effect is sometimes communicated to a distance of two or three feet into the neighbouring rock, but generally not to more than a few inches. The hardened parts sometimes stand up in narrow crests. Where dykes cross, it has been found that one of the planes of intersection of the basalt dykes has been marked by the occurrence of a very narrow band of black pitchstone. The base of the pitchstone pillars of the interposed bed in Corygills is decomposed to a kind of kaolin where it touches the sandstone below.

It is impossible to say what was the geological epoch of the later eruptions of Arran, further than that they were posterior to the red sandstone. They may be as modern as the basaltic eruptions of the north of Ireland.

Fig. 55.—Granitic Ridges, Glen Sannox (Arran).

Granites of Ireland.

Donegal.—The granite axis of Donegal extends from Malin Head for 60 miles S.W. to near Ardara. It is marked by the two great valleys of Glenveagh and Gweebarra, which are nearly in the centre of the granite band which traverses Donegal from Glen in the N.E. to Doocharry Bridge in the S.W. The granite is at first nine miles wide, and afterwards spreads out to a breadth of 18 miles. It is separated by the sea and by quartz rock from the granite of Dunaff Head and Malin Head. There is an isolated patch to the S.E. of the granite axis, divided into two portions by the Barnes More or Great Gap. Still further to the S.E. granitic veins are numerous in the gneissose rocks and metamorphic slates, where Donegal borders Fermanagh, at Beleck and Castle Caldwell. This granite has a stratified structure, the beds are nearly vertical, and run parallel to the great valleys mentioned. The joints are nearly at right angles to the

planes of the cleavage structure. This granite, according to Professor Haughton, is interstratified with the quartz rock, mica-slate, and limestone with which it is associated. This interstratification is seen on both northern and southern outcrops. At Glentchen the granite contains beds of quartzose mica slate, beds of gneiss, and beds of sphene rock, the latter consisting of quartz, orthoclase, and sphene. Nearer the southern boundary thin beds of limestone run vertically in the granite for several miles. On the northern border the granite passes into stratified rocks by insensible gradations, passing into felspathic gneiss with black mica, hornblende slate, and micaceous quartz rock. At Castle Caldwell some of the granite veins consist of quartz, pink orthoclase, white mica, black mica, and schorl, all in large crystals, while other of the veins consist of quartz, pink orthoclase, yellowish-green oligoclase, black mica, sulphuret of molybdenum, and copper pyrites. The percentage of silica in these granites varies from 55 to 75 per cent.

	Donegal Granites.[1]														
	Ardara.	Glen.	Unismenagh.	Glenveagh.	Poison Glen.	Arranmore.	Glen.	Tory Island.	Glenveagh.	Ardmalin.	Poison Glen.	Doocharry Bridge.	Anagarry.	Barnesmore.	Dunlewy.
Silica .	55·20	58·44	65·80	68·00	68·20	68·80	68·96	69·20	69·36	70·00	70·64	72·24	73·04	73·60	75·24
Alumina .	19·28	20·00	12·80	16·80	15·96	16·40	17·40	16·40	16·00	16·36	15·64	14·92	15·20	13·80	13·36
Iron Peroxide .	6·08	6·44	6·64	3·68	3·69	2·60	2·52	2·09	3·03	2·80	2·64	1·63	..	2·00	0·60
Iron Protoxide .	0·46	2·05	0·18	0·65	1·00	0·65	..	1·00	0·30	0·08	..	0·23	..	..	..
Lime .	5·08	4·72	2·92	4·05	2·92	1·75	2·80	1·03	2·29	1·12	2·47	1·68	1·60	0·79	2·25
Magnesia .	3·66	1·57	1·75	0·95	0·78	0·85	0·41	0·85	0·54	0·71	0·15	0·36	0·07	0·50	0·14
Soda . .	4·63	3·81	4·16	4·32	3·75	3·75	3·03	4·20	4·17	4·13	3·81	3·51	2·88	4·29	4·86
Potash .	3·17	2 82	4·40	2·04	4·14	5·31	5·25	5·25	4·47	4·66	4·53	5·10	7·32	5·22	3·27
Manganese Protoxide	0·96	..	..	..	..	..	..	..	..	..	..	0·32	..	..	..
Water .	0·64	..	1·20	..	..	..	..	..	..	..	..	..	..	..	..

North-East of Ireland.—The granites of the north-east of Ireland are chiefly found on the borders of counties Down, Louth, and Armagh, though a small outburst occurs near Cushundun in County Antrim. It forms three natural areas: First, the granite district of Mourne, which is a circular mass nearly nine miles in diameter north of Carlingford Bay; second, the district of Carlingford, five miles in

[1] Haughton, Q. J. G. S., vol. xviii. p. 408.

diameter, which is also circular, and lies to the south of Carlingford Bay; and third, the district of Newry, which extends from Slieve Crook, on the north-east, for twenty-eight miles south-west, to Fork Hill and Jonesborough, with an average breadth of six miles. In the Mourne mountains the granite is fine-grained, and abounds in cavities filled with crystals of the minerals which form the granite. This rock consists of quartz, orthoclase, albite, and green mica. The quartz is of a smoky-brown colour, and occurs in hexagonal crystals in the cavities of the rock. The orthoclase is opaque white. The albite occurs in the interstices of the orthoclase and quartz, the mica is dark green and nearly opaque, and contains an unusually large percentage of iron. Among the accidental minerals are beryl, chrysoberyl, octahedral fluor spar, topaz, and peridote. This granite somewhat resembles the elvans of Cornwall. The mineral composition is stated at quartz 28, orthoclase 44·2, albite 27·8.

	North-East of Ireland Granites.[1]							
	Carlingford.				Newry.			
	First Carlingford.	Second Carlingford.	Granite converted into Syenite.	Wellington Iron.	Newry Quarry.	Goragh Wood Station.	Gneissese Granite, Goragh Wood Station.	Elvan, Newry Quarry.
Silica	70·48	71·41	47·52	71·24	64·60	62·08	66·08	74·20
Alumina	14·24	12·64	28·56	14·36	14·64	15·92	13·52	10·84
Iron Peroxide	3·72	4·76	7·23	3·36	6·04	7·72	6·76	1·88
Iron Protoxide	...	...	...	...	...	...	0·18	...
Lime	1·48	1·80	15·44	1·48	3·16	5·52	1·20	2·84
Magnesia	0·40	0·63	1·48	0·64	2·80	2·16	1·32	trace
Soda	3·66	3·03	...	3·13	4·02	3·34	3·75	4·77
Potash	4·26	5·47	...	4·09	3·15	2·19	2·73	3·12
Loss	1·59	...	...	1·50	1·13	0·89	2·19	0·83

In the Carlingford district there are two varieties of granite which pass into each other; and the summit of the Carlingford mountains is formed of syenite, which passes into the granite in one locality, and also passes into hornblende rock. In this district there are numerous greenstones. According to Dr. Haughton, one variety of granite which has the grains of medium size consists of quartz, felspar, and green mica. The second variety, which is very fine-grained, consists of quartz, white felspar, and hornblende. Although different mineralogically, these granites are very similar chemically;

[1] Haughton, Q. J. G. S., vol. xii. pp. 196–199.

both are potash granites, the first consisting of quartz 20·70, felspar 66·37, mica 12·76, and the second consisting of quartz 17·16, felspar 67·18, hornblende 15·40. The syenites of Carlingford consist of hornblende and anorthite. The formation of anorthite is attributed to the addition of carboniferous limestone of the second variety of granite when fused; and in the locality of Grange Irish, the granitic dykes which pierce the carboniferous limestone are found to be changed into coarse-grained syenite.

In the Newry district, there is potash granite to the south of the town and soda granite to the north. The potash granite is similar to the first-noticed granite of Carlingford. The soda granites are characterised by the presence of jet black mica and reddish translucent felspar.

Leinster.[1]—The granites of the south-east of Ireland occur in the counties of Dublin, Carlow, Kilkenny, Wicklow, and Wexford. Professor Samuel Haughton describes the main chain of granite hills as extending from Booterstown, county Dublin, to Poulmounty in the south of Carlow, within five miles of New Ross. This chain has an unbroken length of sixty-eight miles, and is from eight miles to fifteen miles broad. Secondly, to the east of the main chain, and parallel to it in Wicklow and Wexford, are about twenty isolated districts, where granite breaks through the Cambrian slates. This chain extends forty-three miles from Ballinaclash, county Wicklow, to Camaross Hill, county Wexford.

The granite of the main chain varies but little in appearance, and consists of quartz, orthoclase, silvery grey mica, and black mica. The quartz is uniformly grey and transparent. The orthoclase is invariably white and opaque, and occasionally forms large porphyritic crystals. Dr. Haughton thinks that albite probably occurs, though he has been unable to identify it. The grey mica is in plates varying from $\frac{1}{10}$th of an inch to three inches diameter; and occurs in flat right rhombic prisms, or in hexagonal tables; it belongs to the species called Margarodite. The black mica is only in small quantity; the only accidental minerals are schorl, beryl, apatite, garnet, fluor spar, spodumeme. In chemical composition this granite varies but little, the silica only ranging between 70 and 74. The mineralogical composition is mica 13·37, felspar 61·18, quartz 24·98.

Rev. H. Lloyd (1833) notices that to the south of Dublin, opposite the village of Black Rock, the granite is composed of rounded masses which he thinks to be water-worn and cemented in a granite matrix.[2] The microscopic structure of the granite of Ballyknockan, county Wicklow, has been described by Professor Hull.[3]

[1] Haughton, Quart. Jour. Geol. Soc., vol. xii. 1856, p. 171.

[2] Geol. Soc. Dublin, vol. i. part i. p. 83.

[3] Journal R. Geological Society of Ireland, vol. iv. p. 6; and in Geol. Mag.

	Main Chain of Leinster.[1]										Isolated Granites of Leinster.[2]				
	Three Rock Mountain.	Three Rock Mountain.	Dalkey Quarries.	Ballyknocken.	Fox Rock.	Backstairs Mountain.	Kilballyhugh.	Ballyleigh.	Enniskerry.	Carnsore.	Third Group.	Third Group.	Cushbawn Hill.	Croghan Kinshela.	Coolboy Tinahely, County Wicklow.
Silica .	70·28	70·32	70·38	70·82	73·00	73·20	73·24	73·28	74·24	71·80	66·60	68·56	70·32	80·24	63·80
Alumina .	13·64	16·14	12·64	14·08	13·64	15·48	15·45	12·64	13·64	11·72	13·26	14·44	11·24	12·24	17·60
Iron Peroxide .	2·60	3·20	3·16	3·47	2·44	1·72	1·60	2·00	1·40	3·88	7·32	5·04	4·80	0·72	3·40
Iron Protoxide .	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·50
Lime .	2·04	1·34	2·84	2·65	1·84	0·96	0·99	1·72	1·48	2·12	3·36	3·85	3·01	0·89	2·70
Magnesia .	..	..	0·53	0·31	0·11	..	..	..	..	trace	1·22	0·43	0·73	trace	1·00
Soda . .	2·82	3·39	3·13	2·31	3·53	3·18	3·18	2·97	2·72	3·06	3·60	3·36	3·39	5·58	5·10
Potash .	5·79	4·65	5·90	4·64	4·21	4·80	4·59	4·70	3·95	4·77	2·31	2·78	2·27	0·40	2·61
Loss . .	..	0·96	1·16	1·39	1·20	..	1·20	1·04	1·20	0·95	2·34	1·00	1·62	..	0·76
													Carbonate of Lime.		
													1·62		

The Isolated Granites of Leinster.—The isolated granites differ in mineral composition much more than those of the main chain. They are referred to four geographical groups. The first or western group extends in a broken manner from near Rathdrum, for about 10 miles to Aughrim, and is well seen in Cushbawn Hill. In the north it contains red felspar and black mica; but in most cases it is a fine-grained granite, with grey quartz, white felspar, and minute particles of grey and dark-green mica, so small in quantity that the rock may be said to consist of quartz 17·4 and felspar 82·6. On analysis it contains 70 per cent. of silica; 1·34 of carbonate of lime is supposed to be infiltrated from the overlying limestone gravel.

The second group of these granites consists of Croghan Kinshela and Conna Hill, and has a length of about six miles. On its north are the famous gold mines of Wicklow. This granite is chiefly composed of quartz 38, albite 62, but contains a variable quantity of chlorite, sometimes nearly wanting, sometimes plentiful. The quartz in this rock occurs in small rounded granules. It is a soda-granite, and contains 80 per cent. of silica. The brilliant white colour is due

[1] Haughton, Q. J. G. S., vol. xii. pp. 177, 186.
[2] Ibid., pp. 182, 183, 184; R. Irish Acad., vol. xxiii.

to the albite, but it is sometimes stained by chlorite, which appears to take the place of mica.

The third group of isolated granites commences S.W. of the village of Oulart in County Wexford, and extends at intervals for 15 miles to Camorus Hill. These granites consist of grey quartz, white felspar, which occasionally become yellow or pink, and black mica, which is probably mixed with hornblende. Professor Haughton considers it to consist of quartz 6·44, felspar 89·69, mica 3·60.

The fourth group of granites is at Carnsore, and consists principally of grey quartz and reddish felspar, frequently associated with green mica and a variety of hornblende, which is irregularly distributed. This is a potash granite, and neglecting the mica, consists of quartz 21·50, felspar 78·50.

Hence Professor Haughton concludes that the Leinster granites belong to two types; first, the potash granites of the main chain and of Carnsore; and, secondly, the soda granites of the isolated series. The potash granites are subsequent in date to the Cambrian rocks and older than the carboniferous limestone. The soda granites are also newer than the Cambrian rocks, but there is no evidence of their exact age. In 1858[1] Dr. Haughton regarded the isolated granites as formed by irruption of granite of the main chain adulterated or mixed with the materials of the rocks through which it burst.

Professor Haughton states that the eruptive granites can be distinguished from the metamorphic granite[2] by their felspars never including any lime felspar, and by containing albite in addition to orthoclase. Among such granites he would class those of Cornwall and Devonshire, Leinster, Mourne, and Peterhead. The granites which he believes to be metamorphic contain, in addition to the orthoclase, oligoclase or labradorite, but albite is never found. As examples of such granites may be quoted those of Donegal, Galway, West and Central Scotland, and Aberdeen.

Galway.—A large tract of granite stretches west from the town of Galway to Bertraghboy Bay and Dogs' Bay, which has been described by Mr. Kinahan.[3] Professor Hull, F.R.S.,[4] has examined its microscopic characters. It is a foliated rock, probably of metamorphic origin at Firbogh, in Galway Bay, and consists of quartz, dull waxy felspar probably oligoclase, and dark-green mica in nearly equal proportions, with porphyritic crystals of flesh-coloured orthoclase. The quartz is never crystallised, and envelops all the other minerals. It contains numerous fluid cavities. Orthoclase occurs in small crystals as well as in larger masses. It is penetrated in two directions by irregularly parallel lines, like chains, of microscopic beads. Scattered flakes of brown mica are imbedded both in the silica and felspar. Colourless mica occurs in twisted flakes. There is probably a little magnetite.

[1] Trans. Royal Irish Acad., vol. xxiii. p. 611.
[2] Proc. Royal Society, vols. xvii. xviii.
[3] Explanation of Sheet 105, Geol. Survey, Ireland.
[4] Geological Magazine, May 1873.

Mayo.—A considerable mass of granite extends from N.E. to S.W. in County Mayo. Professor Hull describes[1] that of Aillemore as forming two mountains named Coroock Brack and Knockaskeheen. It is of a grey colour, usually fine-grained, consists of quartz, orthoclase, and probably oligoclase, and dark-green mica. Occasionally it has the aspect of graphic granite. It is traversed by joints which run N. by 10° W. It is surrounded by schists, and is older than the May Hill sandstone.

The orthoclase under the microscope is often cloudy, but sometimes shows cross-banded structure, as in the Firbogh granite. The quartz is similar to that of Galway. The mica often includes grains of magnetite.

This rock is said by Mr. Symes to be a true eruptive granite, without a trace of foliation, and sends veins into the surrounding rocks.

Granite Veins.

Granite Veins.—It is difficult to find a satisfactory example of any extensive tract of granite without the occurrence of granite veins ramifying through the neighbouring rocks. They occur in Cornwall, Cumberland, and Arran, in Ben Cruachan, at Strontian, in Glen Tilt, and generally throughout the Highlands. The same is true for the continent of Europe; and perhaps we nowhere find a better example of the elevation of granite in *a solid form*, than that described by Murchison at the Ord of Caithness. This granite, on its northern flank, supports the old red conglomerate, whilst to the south it occupies a cliff on and near the shore, the verge of which affords a remarkable breccia, compounded from all the beds of the oolitic series that occur on this coast. This breccia of sandstone, shale, and limestone, is tilted off from the granite wherever that rock protrudes upon the shore, whilst the strata are regularly developed where the granite recedes into the interior. No veins or portions of the granite are to be met with in or above the oolitic breccia, which, by its disturbed position, appears to fix the maximum of antiquity of the elevation of the granite as not older than the coralline oolite.

Fig. 56.

Tornidneon.—The granite veins of Tornidneon in Arran pass from a body of very coarse-grained granite through nearly vertical laminæ of dark quartzose clay slate; the line of junction dividing the whole side of a hill. One of the veins encloses fragments of slate, and divides itself into

[1] Hull, Journal of the Geological Society of Ireland, vol. iv. p. 4.

branches which cross the laminæ of slate, cutting off both the quartzose and argillaceous layers. The granite becomes much finer-grained along the veins, and nearly in proportion to their smallness; so that in the narrowest veins it is nearly compact. Strings of fine-grained granite divide the coarser sort.

Glen Tilt.—In Glen Tilt, MacCulloch has described numerous and valuable facts of this nature. At the bridge beyond Forest Lodge, granite, hornblende slate, and crystalline limestone are very curiously associated. Veins of red granite here divide the other rocks, and enclose fragments of them. The singular interlacements of the rocks are here shown by the sketch taken by Professor John Phillips in 1826.

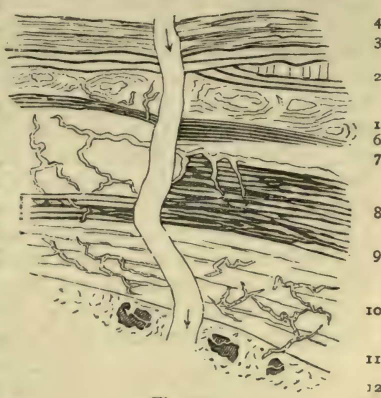


Fig. 57.

1. Crystalline limestone laminated by hornblende and red felspar in curved lines or detached masses, round which the laminæ of limestone bend, crossed by granite and red felspar veins.
2. White quartz rock and red felspar crystallised.
3. Felspathic rock, red, with layers of black hornblende.
4. Limestone laminated with felspar.
5. The same with less felspar.
6. Hornblende and felspar in layers.
7. Laminated limestone.

(*a.*) Red felspar vein—a little quartz.

8, 9. Hornblende, with layers, masses, and veins of white quartz and red fe'spar, which substances often occur together, making binary granite of very large grain.

10. Limestone, with red granite veins.
11. Limestone, red granite veins, and white *calcareous spar veins, which divide the granite veins.*
12. Red granite, composed of red compact or crystallised felspar, white quartz, and black or gray mica, and encloses hornblende masses which are divided by veins of granite ramifying from the general masses of that rock.

Cornwall.—The extremity of Cornwall has long been famous for the great variety of curious phenomena connected with the granite veins which there divide the argillaceous slate, hornblende slate, and greenstone rocks, all included by the miners under the title of killas. So many writers of eminence, both English and foreign, have described and reasoned upon these occurrences, that it is difficult to select from the immense variety. The following is Majendie's account of the veins at Mousehole, three miles south-west of Penzance:—"At this period the clay slate ceases, and the granite commences, forming a promontory which runs out in a southern direction from the central ridge. The slate is of a grey colour; it is in strata nearly

horizontal, but having a slight dip to the east; it increases in hardness near the junction. The granite, which is generally coarse and porphyritic from the large embedded crystals of felspar, becomes here of a finer grain, with black mica and light flesh-red felspar. On the north it laps over the schist. At this spot numerous granite veins, varying in width from about a foot to less than an inch, pass through the slate; the two principal veins proceed nearly east from the hill above, for more than fifty yards, until they are lost in the sea. One of these, not far from its first appearance, is divided and heaved several feet by a cross vein consisting of quartz intermingled with slate; fragments of slate appear also in the granite veins. The most remarkable vein, after proceeding vertically for some distance, suddenly forms an angle, and continues in a direction nearly horizontal, having slate above and below."[1]

The Devonian rock, locally called killas at this place, has much the aspect of greenstone, and it appears generally true that the clay-slate is much altered in character round all the granites of Cornwall and Devon.[2] The veins of granite are generally most fine-grained towards the walls. Von Oeynhausen and Von Dechen mention three principal veins at Mousehole, one $3\frac{1}{2}$ to 10 feet wide; quartz veins cross the direction of the granite veins, and sometimes divide them, and apparently alter their character. Schorl occurs irregularly in the granite, and in some of the quartz veins. The intricate character of the veined masses of Mousehole will be best understood by consulting the diagram (fig. 58), copied from the sketch of the distinguished Prussian geologist above named.

Fig. 58.

At Cape Cornwall a granite vein *heaves* a quartz vein in a direction contrary to the general law. In the Lizard district granite veins divide serpentine.

Veinstones.—Under this name Dr. Sterry Hunt, F.R.S., designates a class of veins which are neither injected from below nor infiltrated from above, but derived from the rock which immediately surrounds a closed fissure in which water accumulated. This origin of felspathic and granitic veins by segregation was first indicated by Daubrée, and subsequently taught by Dana. In schists in the Appalachian region of Canada are veins with flesh-red orthoclase mixed with chlorite and white quartz. Some veins are made up of orthoclase, quartz, and mica; they have the character of coarse granite, and include a number of rare minerals in small quantity. Granitic veinstones abound in the Montalban series in the United States. Sometimes the felspar

[1] Cornwall Geol. Soc. Trans., vol. i.

[2] J. A. Phillips "On so-called Greenstones of Cornwall," Q. J. G. S., vol. xxxii.

crystals are enclosed in vitreous quartz, sometimes quartz lines each side of the vein, or occupies the middle, or alternates with bands of orthoclase, or orthoclase mixed with quartz, as in graphic granite. Garnet and tourmaline are common as accidental minerals. Such veins are distinguished by their shortness and irregularity. These concretionary veins are frequent in the Laurentian rocks of Canada, which are alternations of gneisses and limestones; but they pass on the one hand into metalliferous veins, and on the other into veins with calcite, apatite, and various calcareous and magnesian silicates, accompanied by orthoclase and quartz. Banded structure and drusy cavities are characteristic evidences of deposition from water, though the walls may be coated with hornblende, phlogopite, or other minerals usually accounted igneous.[1]

Syenite of Ailsa Craig.[2]—Ailsa Craig is an island ten miles west of Girvan, 1113 feet high, 1500 yards long, and 1250 wide. It is a fine-grained syenite, showing close parallel vertical joints on the south and west sides. Dykes of dolerite run into it in a N.W. direction.

Phonolite.

The Wolf Rock lies nine miles S.W. of the Land's End, and at high water is covered by the sea to a depth of two feet. The rock has a yellowish grey base containing clear crystals of glassy felspar. Under polarised light, crystals of felspar and nepheline are seen to be embedded in a fine-grained matrix of nepheline, felspar, and hornblende. In thick sections the felspar and nepheline are well-coloured; but in thin sections colours are only shown by the hornblende, the hexagonal sections being black and the rectangular sections white. The felspar also has the aspect of a mosaic of dark and light stones; it frequently encloses crystals of nepheline and hornblende, and gives all the characters of orthoclase; it contains many glass cavities and minute crystals. Hornblende is found in small green prisms sometimes crowded about grains of magnetite.[3]

The greater part of the rock consists of nepheline, in crystals which vary from $\frac{1}{150}$th to $\frac{1}{2000}$th of an inch across. This rock, probably of Primary age, is classed by Mr. Allport as a porphyritic phonolite. The following is the analysis by Mr. J. A. Phillips, F.R.S. :—

Silica	56·46	Magnesia	trace
Alumina	22·29	Phosphoric acid	trace
Peroxide of iron	2·70	Potash	2·81
Protoxide of iron	·97	Soda	11·13
Manganese	trace	Water	2·05
Lime	1·47		

[1] T. Sterry Hunt, Chemical and Geological Essays, 1875, p. 183.
[2] Mem. Geol. Surv. Scot. Explanation Sheet 7, 1869. Arch. Geikie.
[3] Allport, Geol. Mag., vol. viii. p. 247, 1871.

CHAPTER XVII.

THE HISTORY OF VOLCANIC ROCKS.

Method of Study.—Igneous rocks can only be studied with advantage in their natural occurrences on the surface of the country; and the student will always spend his time most profitably who gains practical knowledge of the behaviour and variation of rocks in the field by detailed study of some classical district.

A useful preparation for such an investigation is a preliminary knowledge of the common minerals which combine to compose these rocks. And this can hardly be attained better than by collecting the specimens on the old lava streams of a volcanic district, such as the Auvergne, Siebengebirge, or Eifel; but in cases where such practical work is not immediately convenient, specimens of rock-forming minerals (see p. 22) must be obtained from some trustworthy dealer. When their crystalline forms and other physical properties have been sufficiently examined, duplicate specimens of each should be sliced and mounted for study under the microscope with polarised light, so as to form a standard series, by which similar minerals may be recognised, when they occur in combination in igneous rocks. Having the commoner types of minerals thus prepared, and furnished with a microscope, to which a polariscope is fitted, the student is qualified to begin practical work. He must prepare, or have slices prepared from typical volcanic rocks, and will soon be able to identify the constituent minerals in them by comparison with his types, so that the rock slices will become a series of standards. He will then be in a position to add to the store of knowledge by determining the nature of the rocks found in districts which may come under examination.

The Characters of Minerals in Polarised Light.—The common rock-forming minerals can often be identified under the microscope by their crystalline forms and method of arrangement; but under polarised light identification is more often certain. The following notes on the optical characters of minerals may be useful (but see Rosenbusch: "Mikrosk. Physiog. der petrog. wichtigen Mineralien." 1873):—

Quartz usually shows one colour in the centre, with two or three other colours around it. The colours are very bright and clear in thick slices, while in thin slices they are white or grey blue.

Orthoclase sometimes shows cross-hatching. Occurring in twins,

it usually is blue on one side of the twin plane and yellow on the other, but the colour varies with thickness of the slice, &c.

Oligoclase exhibits many alternations of blue and yellow in thin bands. This condition of repeated twinning is common in triclinic felspar.

Labradorite only assumes a darker tinge when the polariser is rotated, and shows banded structure due to twinning.

Anorthite is distinguished from labradorite by showing brighter colours than the other felspars.

Nepheline.—In thin slices its colours are very pale, and vary, between crossed nicols, from dark milky-blue to brownish-yellow.

Leucite shows no colour, though when the slices are sufficiently thick the mineral has a bluish-white tint, paler than nepheline.

Black Mica gives green, yellow, and brown tints when the section is hexagonal; when cut across the lamellæ, and the plates are very thin, there is a carmine tint.

White Mica, in which the divergence of the optic axes is greater, shows yellow and red colours, but the colours are clear.

Amphibole.—In this the colours may be either pale green or blue, or yellowish, or dark brown between crossed nicols. They are brighter than those of pyroxene. The **Actinolite** variety gives emerald green; **glaucophane**, clear blue; **hypersthene** is intermediate between pyroxene and amphibole; **epidote** is citron yellow to brown.

Pyroxene.—The colours of augite are not so clear as those of epidote, nor so bright as those of olivine. They are often yellow and red, sometimes green-brown and rose, varying with the rock.

Olivine in very thin slices is colourless, but in thicker sections its colours are brilliant red and green. **Apatite** varies from pure white to bluish white or yellowish.

Titanite between crossed nicols gives deep-yellow and brown colours, but less bright than those of augite and hornblende.

Tourmaline is brown or dark green, rarely blue or rose colour. It may be compared with hornblende, biotite, and epidote.

Frequently it is necessary to measure the angles of crystals to identify some minerals with certainty; this can be done by means of graduated circles and a rotating stage, such as are found in Rosenbush's petrological microscope. We have also used crossed spider lines in the eye-piece, one of which is capable of being rotated, as an instrument for measuring crystal angles under the microscope, with the advantage that the object is not moved.

Texture of Igneous Rocks.—The structures of igneous rocks which are most easily recognised, admit of being classed according to the conditions of solidification into three types: first, crystalline; secondly, semi-crystalline; and thirdly, uncrystalline. These divisions are adopted by Professor Zirkel in his "Microscopical Petrography."

(1.) **Crystalline Rocks.**—Granite is the best type of a crystalline rock, in which the texture is *macroscopic*, or such that the crystals may be distinguished by the naked eye; but the same type of crystalline structure may exist when the texture is *cryptocrystalline*, or such

that the crystals can only be recognised under the microscope. No perfect boundary can be drawn between perfectly crystallised rocks and those in which a minute quantity remains of the original material which has not been differentiated into crystals.

(2.) **Semi-crystalline Rocks.**—The semi-crystalline rocks are a large class, in which the greater part of the material is an amorphous substance, through which are scattered crystals that may be either microscopical or macroscopical. The crystals may be few, or so numerous as to form nearly the whole of the rock. These semi-crystalline rocks present several varieties, according to the condition of this uncrystallised material.

First, it may be purely glassy, consisting of glasses which yield no colours in polarised light.

Secondly, the glass may be partially devitrified, by the formation of grains and needles. The needles are usually black and hair-like, the grains angular or rounded. They have been termed crystallites and globulites, but neither polarise, and they are both therefore regarded as glass richer in iron. The dark needles or trichites are aggregated into branched or net-like masses. The globulites are common in dolerites and other basic rocks, but rare in rhyolites.

Third, devitrification may proceed so far that the glass is entirely replaced by such small bodies as those described.

Fourth, the microfelsitic mass sometimes presents an amorphous substance, free from glass, without transparency, and incapable of being resolved into separate particles. This condition is more characteristic of the quartz porphyries and rhyolites than of basic rocks. It will readily be understood that it is often difficult to distinguish the original nature of a rock which has undergone some of these phases of devitrification; and chiefly on this account, the volcanic rocks of the Primary period have only recently been shown to be essentially the same as those of the Tertiary period, but somewhat decomposed.

(3.) **Uncrystalline Rocks.**—The uncrystalline type consists of a volcanic rock which was originally amorphous, sometimes glassy, like obsidian or tachylyte, and often in the microfelsitic state. Between these rocks, therefore, and the semi-crystalline rocks there is a complete transition.

Ground Mass and Base.—Zirkel uses the term *ground mass* to indicate the part of a rock between visible crystals which shows no structure to the unaided eye; but when the rock is examined under the microscope, and a similar homogeneous appearance is seen between crystals, that undifferentiated paste is named *the base;* and it is this base which presents the varied conditions of texture which we have enumerated in semi-crystalline rocks.

Fluxion Structure.—Fluidal structure is a term applied to more or less glassy rocks, in which streams of microliths or needle-like crystals undulate and bend in their arrangement about a larger crystal. Such fluxion structure is often seen in the least crystalline basalts, trachytes, and phonolites. These conditions are best observed under the microscope between crossed nicols, and under a low power. The

appearance seen resembles the curvature and waved lines on some kinds of marbled paper. Those rocks in which the fluidal structure is best developed, are rich in broken crystals.

Microliths.—Among constituents found in the base of some lavas are *microliths*, which may be described as imperfectly formed needle-shaped crystals. They may belong to many minerals, such as felspar, hornblende, augite, mica, or apatite; and if the microlith can be identified, it is referred to its mineral species. Garnets have no tendency to form microliths, and specular iron occurs in six-sided plates. When the microlith is colourless it is a belonite, when it is black and opaque it is a trichite.

Opacite, Ferrite, and Viridite.—Three other terms are used in describing the base of rocks to designate substances which cannot be certainly identified. First, *opacite* exists as black opaque grains, and is found among the products of decomposition of minerals. It may consist of oxides of iron, titanium, manganese, graphite, and various earthy silicates. Secondly, *ferrite* is a rust-coloured material of amorphous form, which cannot be identified, but is probably sesquioxide of iron. Third, *viridite* is a fibrous or scaly-green transparent substance, consisting of silicates of iron and magnesia. It results from the decomposition of olivine, augite, and hornblende. The fibres are referred to such a mineral as delessite, the scales to such a mineral as chlorite.

Propylite.

In treating of the several kinds of volcanic rocks,[1] we have followed the grouping of Richthofen, chiefly because these rocks have been so fully described in elaboration of his researches. And on this account it has seemed desirable to give, in addition to a history of the European volcanic rocks, a statement of the conditions under which such rocks are found and their mineral variations in the western volcanic region of the United States.

Propylite.—Richthofen states that around Bisytritz, in Northern Transylvania, propylite forms cones. It also occurs at Nagybanya and Kapnik in Hungary. Massive eruptions of it are found on the southern slopes of the Carpathians; and it appears in every case to have been ejected through fissures, since no traces of volcanoes of propylite are known in Europe. The rock is always porphyritic, and consists of a microcrystalline paste, of a dark-green or greenish-brown colour, or red and grey. In the ground mass are scattered crystals of white or light-green oligoclase, and dark-green fibrous hornblende. The paste is formed of the same ingredients, with titaniferous iron; so that the colour of the rock is always green, and it closely resembles oligoclase trachyte, and consists of the same ingredients as hornblende-andesite. Some varieties contain rounded grains of quartz, and other varieties hold crystals of augite.

[1] Rosenbusch's "Mikros. Physiographie der massige Gesteine" is a valuable introduction to a knowledge of volcanic rocks, from which we have quoted many facts.

Relation of Propylite to Silver.—Propylite is frequently associated with veins of silver, as in the Carpathian mountains, and more strikingly in North America. It forms one of the walls of the famous Comstock lode. It is connected with silver veins in the Aurora district, with some of those in Silver Mountain, with the Moss lode of Arizona, and with the silver veins of some parts of Mexico.

	American Propylites.[1]			American Quartz-Propylites.			American Diorites.	
	Washoe.	Between Truckee and Montezuma Ranges.	Sheep Corral Cañon.	East of Havallah Mountains.	West of American Flat Washoe.	Foot Hills. Sheep Corral Cañon.	Eldorado Outcrop.	Three Peak Mountain. Shoshone Range.
Silica	58·66	60·33	64·62	66·34	68·44	74·41	56·71	60·20
Alumina	17·90	19·74	11·70	14·80	14·86	2·84	18·36	18·55
Peroxide of iron	...	0·70	...	4·07	...	...	...	...
Protoxide of iron	4·11	2·50	8·39	...	3·80	13·30	6·45	4·37
Manganese	...	trace	...	...	...	...	...	trace
Lime	5·87	3·72	8·96	2·99	1·90	0·40	6·11	4·41
Magnesia	2·03	4·01	1·18	0·92	...	...	3·92	2·20
Soda	2·07	4·36	3·13	5·16	3·22	1·28	3·52	3·20
Potash	3·19	1·62	1·95	3·19	5·08	6·02	2·38	3·87
	...	...	PO^5 trace	CO_2 1·03	CO_2 0·94	...	...	Lithium trace
Loss on Ignition	6·53	3·13	1·02	2·13	2·26	1·79	1·94	2·97

Propylite of the Virginia Mountains.—Propylite is a widely distributed rock in the United States, and is met with in the form of tuffs as well as in solid rock. The most important outburst described by Clarence King occurs in the higher part of the Virginia range, and extends from Pyramid Lake on the south to the Sierra Nevada. Before the propylite was erupted the Virginia mountains consisted of slates, limestones, schists and quartzites, disturbed by intrusive granite. Great masses of diorite had already burst through these, and formed the highest peaks, such as Mount Davidson. Then the propylite was thrown out from fissures, which run in the direction of the range, and extend from the summit of the range to its base on both sides. On the south and east the propylite flood ran to Carson Plain, and on the west to Steamboat Valley; and only the highest portions of the diorite peaks were lifted above the products of this outburst. The eruption was intermittent, and the material was ejected in a viscous condition. The first outbursts were of olive-green propylite, crystalline and porphyritic. The second, on the north and south of Mount Davidson in Washoe, is a propylitic breccia enclosed in an ordinary propylitic matrix. The third out-

[1] U. S. Geol. Surv., Fortieth Parallel, vol. i. p. 560; Table VIII.

burst formed narrow dykes, which often stand up in bold remnants thirty or forty feet above the surface. The texture sometimes becomes fine, compact, and fissile, like hornblendic slate, where it is in contact with diorite. Propylite is more easily decomposed than any other volcanic rock, forming white, yellow, and red clays. North of Tuscarora it is overlain by rhyolite. In the Toyabe range, near Boone Creek, hornblende propylite is overlaid by rhyolite and basalt. At Kaspar's Pass, north of Hot Spring station, at the S.W. of Montezuma range, the propylite is also covered by rhyolite and basalt. At Berkshire Cañon, propylite lies to the east of a lofty mass of melaphyre, and is invaded by quartz-propylite and andesite, and overflowed by trachyte, which in turn is covered by rhyolite, succeeded by basalt.

Minerals in Propylite.—The green hornblende of propylite is frequently changed into epidote, a change which is never seen in the brown hornblende of andesites. Frequently the felspar crystals are filled with hornblende material, which is changed into bright yellow epidote in the Washoe country. Apatite occurs in short thick rounded prisms, having a hexagonal section. In Sheep Corral Cañon the propylite is grey, and in the Truckee and Montezuma ranges the low hills of propylite have a yellowish green-grey colour. In the Fish Creek mountains of Nevada, the hornblende is composed of aggregates of green microliths; and augite occurs which is remarkable for its pale-yellow colour; brown mica and apatite are found. In Storm Cañon the rock is pale yellow and reddish grey. The hornblende in andesite never exhibits the parallel staff structure seen in propylite. At Tuscarora, in the Cortez range, green and dark-brown hornblende occur together.

Quartz Propylite.—In that part of the Cortez range which lies south of the Humboldt river is a mass of propylite, with quartz propylite resting upon it and forming the summit of Cortez peak. At Papoose Peak the quartz propylites again come to the surface, extend for about eight miles, and then pass beneath overlying dacite. The general colour of the surface is soft grey, pinkish and salmon colour, varied with green and olive hornblende. The ground mass consists of clear dark plagioclase, more or less fibrous hornblende, microscopic quartz, with fluid cavities sometimes including cubes of salt. The hornblende has the prismatic staff-like form characteristic of the propylitic rocks. There are the usual titanites. The larger felspars are all dull and slightly kaolinised. At Waggon Cañon the rock contains a few laminæ of brown mica. Biotite seems to be characteristic of the latest injections. Quartz propylite has the aspect of having been erupted in an almost solid condition, showing no tendency to spread out into thin sheets. According to Zirkel, one of the finest exhibitions of this rock is in Berkshire Cañon, Virginia range; the ground mass is grey, rich in macroscopical crystals of dark-green hornblende, and dust of hornblende in laminæ, crowds all the larger felspars. In some localities apatite is present, and occasionally there is a little sanidine. The rock at Cortez peak, seen

under the microscope, presents the aspect of being perforated with innumerable pinholes from the abundance of minute quartz grains.

Quartz propylite forms the hills of Golconda. It is a dark-grey yellow rock, with clear quartz grains about the size of peppercorns. The larger felspars are more or less decomposed. The quartz contains fluid inclusions with moving bubbles, and rather resembles that of diorites in the matter of inclusions. No quartz is visible in the ground mass. Propylites vary greatly in their percentage of silica; and in chemical composition may be instructively compared with diorites, syenites, and certain slates.

Andesites.

Andesites are rocks which consist typically of crystals of oligoclase and columnar hornblende, combined with more or less of a glassy ground mass, small particles of magnetic iron, and a few flakes of mica. Augite, olivine, magnetite, and hauyine are occasionally present. Andesites vary in colour from grey to dark green, and when hornblende abounds may be dark brown or black. They vary chiefly in possessing or wanting an amorphous base, and, when a base exists, in the relative proportion of crystals which it includes. The commonest type of andesite is porphyritic, with a microcrystalline ground mass which has large crystals developed in it. They are chiefly of felspar, but include hornblende, mica, and quartz. Chemical analysis sometimes yields as much silica as occurs in a dacite. Andesites sometimes exhibit a fluid structure, characterised by a parallel arrangement of small, slender crystals, or by the extension of such crystals in curves round larger particles.

Hornblende-andesite is commonly regarded as the volcanic equi-

	Quartzose Hornblende-Andesite.				Quartzless Hornblende-Andesite.			Augite Andesite.		
	Besobdal.	Ararat.	Ararat.	Between Keschet and Kobi.	Wolkenburg.	Stenzelberg.	Java.	Iceland.	Portillo, Teneriffe.	Heda Lava, 1845.
Silica	76·66	69·47	65·46	61·13	62·38	59·22	57·60	60·06	57·88	54·76
Alumina	12·05	14·98	15·36	16·44	16·88	13·59	20·53	16·59	19·09	13·61
Peroxide of iron	2·39	2·31	...	...	7·33	5·55	...	...	...	...
Protoxide of iron	1·08	1·04	6·65	9·23	...	4·03	8·76	11·37	8·92	15·60
Manganese	...	...	...	...	...	...	...	...	...	...
Lime	1·25	4·68	4·24	6·25	3·49	5·13	6·66	5·56	3·65	6·44
Magnesia	trace	0·98	2·11	3·76	0·82	1·66	1·70	2·40	trace	1·35
Soda	3·55	4·46	4·09	} 2·99	4·42	5·31	3·04	3·60	} 9·64	3·41
Potash	2·94	1·46	1·33		2·94	4·64	1·46	1·45		1·21
Loss	1·12	0·35	0·34	0·44	Water 0·87	1·25	...	...	...	...

valent of diorite; and though mica is more characteristic of diorite than of andesite, most of the varieties of diorite may be paralleled by varieties of this rock. When andesites are decomposed their percentage of silica is much reduced. Koch divides the Hungarian andesites into seven varieties, of which two are classed by Rosenbusch as augite-andesite, and five as hornblende-andesite.

The latter comprise—(1.) Labrador-biotite-garnet andesite; (2.) Labrador-biotite-garnet-augite andesite; (3.) Labrador-amphibole andesite; (4.) Labrador-amphibole-augite andesite; and (5.) Labrador-amphibole-biotite andesite. The minerals thus named occur as crystals in a ground mass, which may be clear as glass, or opaque with crystallites, or rich in orthoclase, as in (1) and (2).

Concretionary Inclusions in Andesite.—The hornblende andesites of the Siebengebirge are remarkable for the concretions and small angular inclusions which they contain. The concretions are well developed at Great and Little Rosenau, and in the Stenzelberg, where they are known to the quarrymen as black granite. They vary from an inch or two in size to a diameter of many inches, and consist of conspicuous columns of hornblende imbedded in a ground mass of andesite. The size of the hornblende crystals and the amount of ground mass between them both vary. When the proportion of hornblende is small, the external shape of the concretion may be undefined, but when the hornblende crystals are in contact, and include the matrix between them, then the external form of the concretion is that of hornblende, as well defined as though the matrix were limited to the centre. Large porphyritic crystals of compact hornblende occur. The crystals appear to have grown gradually at the expense of the surrounding rock, the large forms being built up by the gradual increase in size and blending of many small crystals. In the augite-andesite of the Lowenburg we find similar concretions, only the section is octagonal, and therefore presumably determined by the augite. The texture of these concretions is often the finest possible. The separation between the concretion and the surrounding rock is clean and easy, as though a slight film of kaolin parted them. These concretions are not unlike the mica concretions in granite already described, which may have had a like origin. At Little Rosenau silica sometimes separates so as to form quartz veins in the andesite; the ground mass is cryptocrystalline. It contains, with crystals of plagioclase and oligoclase, much hornblende; but sometimes biotite and augite replace hornblende. The percentage of silica varies from 46 to 51.

Mineral Condition of Andesite.—The plagioclase is usually microtine in the glassy varieties of the rock; but in some dacites staff-like crystals of triclinic felspars are frequently aggregated into compound crystals; and it may be that the plagioclase is partly labradorite and partly oligoclase, with some other felspars. The crystals contain inclusions of the base, inclusions of glass and steam cavities, microliths, and occasional fluid cavities. In Hungary and Transylvania fluid cavities abound in dacite, and are absent in andesite. The crystals sometimes are made of fragments united together, some-

times they are more or less decomposed, especially in the andesites of the Stenzelberg in the Siebengebirge. Sanidine is often present. Magnesia-mica occurs in dark-brown or red hexagonal plates, frequently surrounded and penetrated by magnetite. It is usually fresh, always occurs in large plates, and is absent from the ground mass. Hornblende is usually found in prismatic crystals, either brown or green, commonly green when the rock contains quartz. When hornblende is brown, it is usually surrounded by magnetite; it then contains ovoid inclusions of glass. The mineral is sometimes decomposed in the greenstone-like dacites. Like mica, it rarely occurs as a part of the ground mass. Augite occurs in small grains and columns as a constituent of the ground mass, and also in crystals, but is less abundant than hornblende and mica. It is not decomposed. Quartz occurs in grains and crystals in variable proportion in many andesites. It differs from the quartz of rhyolite, and resembles that of quartz-porphyry in rarely containing glass inclusions; and it abounds in fluid inclusions, with cubic crystals, except in the Department of Var.

Tridymite is rare, but is seen in the hornblende-andesite of Dubnik. Apatite occurs in long colourless needles, and in short crystals tinged blue or brown. It is common in the Stenzelberg in the Siebengebirge, and is always present in the Sengelberg, near Salz in the Westerwald. Titanite is a common accessory mineral in the Siebengebirge, the Department of Var, and Tres Montañas in Canary. Hauyine is characteristic of the andesites of the Canaries. Garnet is found in biotite-andesites near Buda-Pest, and some other Hungarian localities. As products of decomposition, andesites contain opals and chalcedony in Servia and Hungary.[1]

Localities for Andesites.—Among the more important European localities for andesites are Shemnitz, Kremnitz, the St. Andrä-Visegrad Mountains, near Buda-Pest in Hungary; the Transylvanian Erzgebirge, the south of Servia, the Smrkouzgebirge in Styria; at Stary Swietlan, near Banau in Moravia, where the rock abounds in siderite, calcite, and various carbonates.

In the Auvergne hornblende-andesites are seen in the lava from the Puy de Moutchié, Rigolet-Haut, and Plateau de Durbize, where they make a transition towards trachytes. A rock free from augite occurs in the valley of the Dordogne near Mont Dore. These andesites sometimes contain a little crystallised quartz, as at the foot of the Brüngelsberg in the Rhöndorf Valley, in the Great Breiberg, and at Kelberg in the Eifel; at the Puy de Chaumont and Liorant in Cantal, and many localities in Hungary, Moravia, and other regions.

In Italy andesites occur in the Eganean Hills at Monte di Ferro di gran Pietra, Monte della Croce and Teolo.

In the Andes of Ecuador at Pululagua, the andesite is almost free from augite. A similar rock occurs at Toluca in Mexico, but it contains quartz, olivine, hornblende, and biotite.

Hornblende-andesite is met with in the Caucasus near Kasbek.

[1] Rosenbusch: Min. Physiog.

American Andesites.—In the United States andesites are more widely distributed than propylites. They extend in scattered exposures from the Cedar Mountains, in the great Salt Lake desert, to California, and generally appear as massive eruptions. The relics of an enormous crater at Lassen's Peak indicate an immense andesite volcano; and andesite volcanoes extend at intervals along the axis of the Sierra Nevada and Cascade ranges. As in Europe, the rock is divided into three groups, termed hornblende-andesite, dacite, and augite-andesite.

	American Andesites.[1]				American Quartz-Andesites (Dacites).	
	N.E. of American Flat, Washoe.	North of Gold Hill Peak, Washoe.	Pallisade Cañon.	Washoe Mountains.	Near American City, Washoe.	Shoshone Peak.
Silica	58·33	61·12	62·71	67·63	69·30	70·25
Alumina	18·17	11·61	12·10	18·08	17·9	14·90
Peroxide of iron	...	11·64	14·79	2·17	...	2·57
Protoxide of iron	6·03	...	...		4·1	1·76
Manganese	...	...	...	trace	...	trace
Lime	6·19	4·33	8·34	3·16	1·6	2·39
Magnesia	2·40	0·61	1·31	1·14	1·3	0·83
Soda	3·20	3·85	0·73	2·87	2·0	3·24
Potash	3·02	3·52	1·15	3·86	3·6	3·22
Loss on ignition	0·76	4·35	...	1·49	2·1	1·51

The hornblende-andesite described by Clarence King, frequently exhibits on weathering a lavender tint, but, freshly broken, is dark brownish, with a compact, homogeneous, half-glassy matrix, including small white crystals of plagioclase, occasional brown micas, the lamellar form of hornblende distinctive of andesite, and a few rounded grains of quartz. This rock is seen on the Divide between Gosiute Valley and Deep Creek. Andesites are found in the Cortes range breaking through the propylite of the Tuscarora region where the rock is dark, containing black hornblende and bright plagioclase in a greenish-grey ground mass. At Carlin Peaks in the Cortes range, the dark-grey andesite rises in a mass 1200 feet above the surrounding rhyolites. At the head of Clan Alpine Cañon the summits of the Augusta range are formed of andesite, which shows a rudely columnar structure. The long hornblende prisms have a rude parallel arrangement, and under the microscope the crystals of hornblende are often seen to be fractured, with the pieces displaced. Sometimes there is a percentage of sanidine in the rock, which gives a roughness to its weathered surface. At the upper end of the cañon of Truckee River the andesites

[1] U. S. Geol. Surv., Fortieth Parallel, vol. i. p. 576; Table IX.

are fully 12,000 feet thick, and often have the aspect of trachyte, a condition which varies with the quantity of orthoclase.

In the Washoe district three zones of fissures occur through which hornblende-andesite was poured out so as sometimes to cut the diorite and propylite, and form table-like masses. The rock poured out from the dykes in Crown Point ravine is 100 feet thick, but the most important spread covers the country near Devil's Gate in Gold Cañon. Nearly all the felspar is fresh plagioclase, with rare sanidine in Carlsbad twins. The hornblende is decomposed into a light-green substance, and the rock contains no augite, biotite, quartz, tridymite, or olivine. The ground mass is a dark-grey aggregate of ledge-shaped felspars, felspar microliths, and grains of magnetite, with a yellowish half-glassy base, as in the andesites of the Siebengebirge. Many varieties of andesite occur on the south side of the entrance to Truckee Cañon. The ground mass varies in colour from grey to reddish. The felspars often contain glassy or half-glassy grains. When augite, which is greenish, occurs, it is rich in glass inclusions, which are always absent from the brown hornblende, as in the Siebengebirge in Hungary; but at times no large hornblende crystals are developed. A typical andesite occurs in Berkshire Cañon, where the rock contains no augite. Half-glassy andesite is found on the west shore of Pyramid Lake in Nevada. The ground mass is made up of colourless felspar, brownish microliths, magnetite, and a brown glass. Characteristic andesites occur in the Augusta Mountains in Nevada, and one from Augusta Cañon resembles the andesite of the Wolkenburg, having hornblende crystals a millimetre long, usually fractured, sometimes into thirty or forty pieces. Above Tuscarora, andesite has a brownish-grey felsitic ground mass, with a macroscopical plagioclase and green hornblende. Multitudes of black trichites give a wavy fluidal structure to the rock. Some of the andesites in the Washoe Mountains are remarkable for the laminæ of brown mica, so that they might be termed mica-andesites, especially as the quantity of hornblende is very small.

Distinction between Propylite and Andesite.—The chief constituents of propylite and andesite are identical. They are, however, easily distinguished by observation in the field. Zirkel observes that the propylite ground mass is greenish grey, while the andesite ground mass is pure grey or brown; propylite is rich in minute particles of hornblende, while andesite only contains large crystals of hornblende; propylite felspars are filled with hornblende dust, while the andesite felspars are free from it. The hornblende in propylite is green, but in andesite it is almost invariably brown, and has a black border never seen in propylite. Propylite hornblende is built up of thin needles, and therefore does not cleave. This is never seen in andesite. Microscopical epidote is common in propylite, but is almost unknown in andesite. A glassy propylitic ground mass is unknown, while andesites sometimes have a half-glassy ground mass.

Dacite.

Dacites are quartz-hornblende andesites. They were associated with quartz-trachytes till distinguished by Stache. Their colour is always of a blackish grey-green or dark-brown. The texture is either compact or granular, and typically the rock consists of quartz, oligoclase, and hornblende, probably with a second felspar, and occasionally mica, with which may be associated a little augite and olivine. Dacites differ from andesite in the character of the ground mass, which when present in dacite has a rhyolitic structure with a tendency to form spherulites, while the andesite ground mass is an aggregate of microliths.

Hungarian Dacites.—In Hungary and Transylvania the dacites have no glassy base, and have been divided by Doelter according to their resemblance to granite, trachyte, and porphyry. Some, as at Rodna and the Vlegyasza Mountains, have no true ground mass, but a fine-grained matrix, with isolated larger crystals, and present the conditions of granite. Near Rodna, biotite is sometimes so abundant as to form a biotite dacite, and the trachyte dacite is generally rich in biotite and poor in sanidine, with scattered particles of quartz, which, however, does not occur here in the ground mass. In the neighbourhood of Nagyag the porphyritic dacites take on the aspect of quartz-porphyries. The dacites around Kapnik often contain small masses with a glassy base, and frequently include pyrite. Timazite is a rock sometimes to be classed with the dacites, and sometimes with the andesites. At Les Crottes, in the Department of Var, the dacite has a granitic texture, while at St. Raphael the rock is microfelsitic. Both these dacites are rich in sanidine, the crystals sometimes being 20 mm. long, so that the rock approximates towards rhyolite.

Dacites also occur at Neu Prevali in Carinthia and Monte Alto in the Euganean Hills. Among the specimens which have been analysed are examples from Besobdal, Ararat, Kasbek, Ebendaher, and between Keshet and Kobi. A dacite from the volcano of Mojanda in Ecuador has a microcrystalline ground mass which includes rounded grains of quartz, andesine, hornblende, and biotite.

American Dacites.—In the eastern half of the Cortez range dacite forms a nearly continuous field for a distance of fourteen or fifteen miles, but behaves like granite, forming massive eruptions 15,000 feet thick, and shows no tendency to extend itself laterally from the region of fissure or to form sheets. Its prevailing character varies, and the colour varies from purple to chocolate and brown, though growing pale to the north of Waggon Cañon, where the tints are olives and greys. At the south it is covered with rhyolite, and on the east is overlain for many miles by basalt. The behaviour of this rock in the field is more like propylite than andesite, and in hand specimens it is not easily distinguished from quartz-propylite. Dacite wants the resinous lustre and glassy fracture of the andesites. The

crystals of felspar are often decomposed, and the rock is sometimes brecciated. North of Waggon Cañon the quartz crystals in the rock are very dark, and rarely visible to the eye. But at Shoshone Peak the quartz grains are frequently from one-eighth to one-quarter inch in diameter, and here the ground mass is sometimes so coarse that the crystals may be distinguished by the eye. Dacites are also well seen in the Virginia range, and there the large quartz grains contain fluid inclusions, and frequently stand out prominently on the smooth weathered surface. The dacite breccia, which breaks through the purple dacite of this range, contains a good deal of dark-brown magnesian mica, as well as more free quartz than the earlier rock. Belonging to the close of the eruption in this region is an apple-green dacite, which is richest of all in quartz, and the grains are frequently double six-sided pyramids.

In the hills about American City, Washoe, the ground mass of the dacite is brownish or greenish grey, and contains striated felspar and quartz grains as large as peas. Sometimes the structure of the ground mass is rhyolitic, but the rock is distinguished from rhyolite by its plagioclase and hornblende. The ground mass may be minutely spherulitic. Fluid inclusions occur in the felspar crystals, but are absent from the quartz, and sometimes the felspar is speckled with calcite. The hornblende crystals contain yellowish-green viridite, rhombohedral calcite, brownish-red oxide of iron, and yellowish-green epidote, which almost replace the hornblende. The circumstance that, on analysis, the potash is usually equal to the soda, suggests the presence of sanidine in the ground mass.

Trachyte.

Trachytes are felsite-like rocks, which abound in sanidine. They are regarded as the volcanic equivalents of syenite, and as corresponding to the old quartzless porphyries. The trachytes of some parts of the Elkhead range, and other districts in North America, have quartz as a normal constituent; and thus, on the one hand, trachyte closely approximates towards rhyolite just as the trachytic rocks in Washoe approximate towards andesite, owing to the amount of their plagioclase.

While sanidine is always the principal constituent of trachyte, it is associated with plagioclase, and hornblende, biotite, or augite; or all of these minerals may be among its constituents, but they always occur in relatively small quantities. Magnetite, titanite, and apatite are usually associated with them, but are unimportant as constituents of the rock.

Sanidine commonly occurs in crystals, which show a tabular or ledge-like section. The regular outer border may be absent, and the entire rock occasionally may be granular. Sanidine crystals are usually Carlsbad twins, but sometimes simple prisms. Baveno twins are mentioned by Rosenbusch from the dark trachyte of Toreggia in the Euganian Hills, and from the Puy de Dôme. Sanidine is often in

fragments conspicuous for their irregular corners and angles; and not unfrequently complete sanidine crystals are seen, when polarised, to be a cemented agglomerate of angular sanidine, so that two processes of crystallisation appear to have taken place in the rock in succession, one dating perhaps before the eruption, and the other after it. At Capo Negro in Ischia, the reddish lavas have the sanidine in parallel threads, but the crystalline arrangement is sometimes in concentric strips, and a crystal often shows zones of growth in the interior.

The plagioclase probably includes several different felspars. Tschermak has proposed to distinguish plagioclase of glassy texture in andesites as microtine. The sanidine is frequently invested by plagioclase; and this condition is well seen in the trachyte of Battaglia, in the Euganean Hills.

	American Trachytes.[1]					
	Truckee Ferry, Nevada.	Between Slater's River and Snake River.	Purple Hill, Truckee Cañon.	Between North and Middle Parks.	Peoquop Range.	Shoshone Falls.
Silica . . .	50·36	53·25	56·45	61·95	67·81	70·30
Alumina . .	17·00	14·42	19·85	15·80	15·83	13·65
Peroxide of iron .	6·12	trace	4·95	trace	trace	...
Protoxide of iron .	3·84	6·00	0·97	5·76	3·41	5·41
Manganese . .	0·30	trace	0·11	...	...	trace
Lime . . .	8·85	6·01	7·70	4·24	3·66	1·92
Magnesia . .	3·02	5·06	2·66	2·63	1·36	0·40
Soda . . .	3·21	3·13	3·16	4·50	5·10	3·45
Potash . . .	1·95	4·58	3·84	3·51	0·67	4·50
Lithium . .	...	...	trace	trace	trace	...
	CO_2+HO				CO_2 0·49	
Loss on ignition	5·35	7·63	0·38	1·34	1·73	0·56

Hornblende sometimes occurs in well-developed crystals, sometimes in ill-defined grains. It is distinguished with difficulty from augite; the cleavage being the only satisfactory means of differentiation, and in some small columnar crystals this is absent. Hornblende in trachyte is almost invariably dark brown, but is green at Mocsar and Tepla in Hungary; and is often green when found in microliths. It is sometimes enveloped in magnetite, and may contain microliths of apatite, and glass and gas inclusions. In the ground mass, hornblende occurs in bundles of small needles, like those seen in phonolite. Hornblende occurs alone in the trachytes of the Azores, at Kieshübel near Schemnitz, and at Kühlsbrunnen in the

[1] U. S. Geol. Surv., Fortieth Parallel, vol. i. p. 604; Table X.

Siebengebirge; it is associated with augite in the trachytes of Kremnitz, of Alsberg in the Rhön, and at Dernbach near Montabaur, and Castelnuova in the Euganean Hills; it is associated with biotite in some trachytes of the Siebengebirge, and in other trachytes hornblende is absent.

Augite may occur in microscopic or macroscopic crystals, which may be well defined and regular, or irregular, or in columns or grains. Twin crystals are frequent, as are fractured crystals. The inclusions comprise glass, magnetite, and microliths of apatite. According to the position of the cleavage so is the colour of the crystal. It is often green when the axis is parallel to the short diagonal of the nicol, and reddish brown when the axis is perpendicular to it. Augite is not so liable to decomposition as hornblende or biotite.

Biotite is not known in the ground mass of trachyte. It occurs in thin hexagonal plates, which are often surrounded with magnetite; the colour is deep brown, but exceptionally may be blood-red, as in the Vallée de la Cour in the Auvergne, at Capo Negro in Ischia, and at Mocsar in Hungary. Biotite is also found in Italian trachytes, at Venda di Teolo, and Monte Zacon in the Euganean Hills. In the Auvergne it is found in the trachytes of Mont Dore, Val de l'Enfer, Plateau de Durbieze, Ravin de la Craie, and in these French localities is associated with augite.

Apatite usually occurs in long needles with hexagonal section; but it is also found in short thick columns, of a grey tint, which may incline to brown, blue, or violet. It abounds in some of the bombs of trachyte at the Laacher See, and at Alsberg in the Rhön. It is less abundant in the Drachenfels; and it is found in the trachyte of Dernbach near Montabaur, and near Kelberg in the Eifel.

Magnetite is scattered in the ground mass in grains and in crystals. It is often adherent to the crystals of augite or hornblende, but never adheres to felspar.

The accessory minerals are titanite, olivine, sodalite, hauyine, and nosea, with quartz and tridymite; though in American trachytes, quartz and olivine both occasionally become important constituents. Leucite occurs sparingly in the trachyte of Arso-Stromes.

North American Trachytes.—Clarence King distinguishes four important areas of trachyte, separated from each other by intervals of four degrees of longitude in the region explored by the Fortieth Parallel Survey. These masses occur in the Rocky Mountains, in the Wahsatch range and Salt Lake region, in the Pinon and Cortez ranges, and in the Virginia and Lake ranges near Pyramid Lake. Several of these masses of trachyte have been forced out through great fissures, which can sometimes be traced to lines of fault.

From the hills at the foot of the Washoe range a flood of trachyte extends 40 miles to Pyramid Lake, and in this district caps all the prominent hills. Zirkel remarks that the whole of this mass has been ejected through a narrow dyke less than 100 feet wide, which pierces propylite in the pass north of Gould and Curry mill.

Much of this overflow consists of breccias, in which the fragments range from the size of a pebble to a diameter of 20 feet. The breccias are capped with sanidine trachyte, varying from 100 to 1000 feet in thickness. The older trachytes are rich in plagioclase, though sanidine slightly preponderates; and they contain more brown hornblende than the newer rocks, and thus approximate to andesites. Such trachytes are seen in Mount Rose and Sugarloaf. The newer trachytes are poor in plagioclase, richer in sanidine, contain much less hornblende, and are usually rich in laminæ of biotite. The felspar frequently contains kernels of yellowish-brown glass, and the hornblende is intermediate in colour between green and brown. Aggregations of tridymite occur like those in the trachytes of the Siebenbürgen in Hungary, the Euganean Hills in North Italy, Mont Dore, and the Puy de Dôme in Central France. In the north and middle parks, cretaceous rocks are dislocated, and have blocks and fragments wedged in the flood of lava. Some of the hills and cones of this district are termed by Zirkel granite porphyries, and by Clarence King trachytoid porphyry. They have a fine-grained and nearly homogeneous ground mass, which consists of orthoclase quartz and a little hornblende, with occasionally plagioclase, apatite, titanite, magnetite, and pyrite. The hornblende is green, and the quartz contains fluid inclusions, but no glass; while in Steve's ridge the hornblende is brown, and the quartz contains glass. In the Henry mountains, Gilbert found both green and brown hornblende together in trachyte, where the quartz contained fluid inclusions.

Zirkel remarks of the quartz trachyte of Steve's ridge in the Elkhead Mountains, that the sanidine crystals are more than an inch long, and the rock closely resembles the trachyte of the Drachenfels; but the felspar, though behaving like sanidine, has the crystal faces which characterise the old compact and dull orthoclase of porphyritic granite and felsite porphyry. The rock also contains grains of quartz of the size of peas, which are broken by many cracks; but there is no microscopical quartz. In other localities, as at Camel Peak in the Elkhead Mountains, olivine occurs with the quartz, and the rock has augite for the predominant mineral. But at the Little Snake River in Colorado the cracked quartz occurs in grains as large as hazel nuts, with large glassy sanidine crystals, and large plates of mica; but shows much augite in the ground mass. At City Creek in the Wahsatch range, microscopic cavities in the rock are encrusted in tridymite. Tridymite occurs at Silver Creek, near Kimball's station.

The rocks to the west of the Elkhead Mountains, and which extend from Hantz Peak to Camel Peak and south from Steve's Ridge in a broad field 35 miles long, are all sanidine trachytes. Some have a rough porous crystalline ground mass in which cracked grains of quartz occur like those of rhyolite, but there is no quartz in the ground mass.

Besides these minerals the trachyte there contains hornblende, a

little mica, a comparatively large amount of augite, and some olivine. The rock forms rounded dome-shaped hills and sharp cones.

On Skellig's Ridge a dyke of trachyte from 20 to 50 feet thick rises out of the sandstone to a height of 150 feet, and extends with vertical walls and horizontal columnar structure for five or six miles, with only one break.

The walls are pitted wherever the grains of quartz have weathered from its surface, and they here occur in double six-sided pyramids. This rock combines the constituents of basalt and rhyolite.

Many American trachytes are remarkable for the quantity of their augite. Thus in the hills between Sheep Corral Cañon and Wadsworth, the trachytes contain abundance of sanidine, associated with pale-green augite, brown hornblende, and some plagioclase in a ground mass of colourless crystals and microliths. At Truckee Ferry the augite prisms are grouped in oval, imperfectly radial accumulations, and another example of augite trachytes is seen between Green River and Bitter Creek.

Near the Wahsatch Range so little of the ground mass is left that the trachyte has frequently a granitoid aspect.

Near Salt Lake City tridymite and quartz occur together in the purple trachyte; and the hornblende crystals contain fluid inclusions with moving bubbles as well as simple gas cavities. The augite crystals are here free from the magnetite so characteristic of basalts. In the upper valley of Susan Creek the trachyte contains granular aggregations of rose-coloured garnets and hexagonal grains of hauyine. Trachytes vary in colour, but are commonly tints of green, grey, and purple, and make transitions on the one hand to the tints of the rhyolites, and through the black varieties approximate to the augite andesites and basalts.

Trachyte eruptions are usually free from lines of bedding, by which the material may be traced up to the vent from which it flowed. In the North-American region it may have either rhyolite or basalt resting upon it.

Phonolite.

Phonolite is defined as a quartzless rock, consisting of a combination of sanidine, with nepheline and leucite. Hence it is essentially a nepheline or leucitic trachyte, and has the same relation to trachyte that nepheline-syenite bears to syenite. Phonolite is probably a volcanic representative of nepheline-syenite. There is no known combination of orthoclase and leucite in the older series of rocks. Though these minerals predominate in phonolite, pyroxene and amphibole are essential though subordinate constituents, and hauyine is often abundant. Titanite, apatite, and magnetic iron are diffused in the ground mass. Plagioclase is absent in most true phonolites, and, when present, is as rare as in the mica-syenite, called minette. Sanidine occurs in long rod-shaped crystals, which may form the greater part of the rock, or occur sparingly between the

nepheline and leucite. Nepheline is often as important as sanidine in the ground mass. It may give six-sided or quadrate sections. This mineral is fresh and clear as water, and not easily determined. Like leucite, which also enters the ground mass, it may occur in microscopic crystals. Plagioclase occurs in the phonolites of the Auvergne, which are poor in nepheline, and is rare in the phonolites of the Rhön and the Kaiserstuhl. Nosean and hauyine may be absent from phonolites which contain no nepheline; but usually both these minerals are more or less important. Hauyine may be macroscopic as well as microscopic: its colour is variable, black, brown, blue, yellow, green, or colourless. It is rare for hornblende to occur, unless associated with augite, and frequently the augite predominates. The larger crystals of hornblende may be brown or green. Hornblende-bearing phonolites occur at Teplitz and Aussig, and at Spansdorf and Grosspriesen, and on the road from Mont Dore to Murat, &c., hornblende occurs with much green augite. Both those minerals may occur as porphyritic crystals or as part of the ground mass. More rarely augite is present without any hornblende. The leucitic rocks are richest in augite. Many phonolites in Cantal and Heidelberg contain magnesia-mica. The apatite is blue and brown, and may form thick prisms. Titanite is either greenish yellow, clear yellow, or orange-red. Tridymite is common in the phonolite at Aussig. Olivine occurs at the Roche Sanadoire, and some other minerals occur exceptionally in other localities. The base is often globulitic, as at Hohenwiel. It may be amorphous or micro-felsitic in some places, or occasionally granitic. A phonolite-like obsidian is found at Teneriffe. Occasionally when the rock has a trachytic character it is porous, and often has the cavities filled with zeolites. Spotted phonolites are found in Teneriffe. The phonolites include seven mineral varieties, which may be grouped as nepheline-phonolite, nosean or hauyine phonolite, and sanidine-phonolite.

Rhyolite.

The name rhyolite was first used by Von Richthofen in 1860, to define Hungarian and Transylvanian lavas, which consist of crystals of quartz and sanidine, scattered through a felsitic ground mass. A similar rock is well seen in the Lipari Islands, from which it was named Liparite, by Justus Roth, in 1861. It has been found in the Euganean Hills, in Rhenish Prussia, the Auvergne, Iceland, the Rocky Mountain region of North America, the Northern Island of New Zealand, and several of the islands of the Greek Archipelago.

Rhyolites are the volcanic equivalents of granites, and are identical with quartz porphyry, quartz felsite, and felsitic pitchstone, associated with the Primary strata.

No volcanic rock presents greater varieties of texture and microscopic structure than rhyolite. Some rhyolites are entirely crystalline; others have crystals in greater or less quantity scattered through an amorphous base; while a third type is absolutely free from

crystals. The first of these is the rarest, and is usually known as granitic rhyolite or nevadite. The second type is perhaps the most typical, being common wherever rhyolites occur. It corresponds to the old quartz porphyry and felsite. The third type comprises the hyaline rhyolites, which include perlite, obsidian, and pumice, and includes the old felsitic pitchstones. No region has yielded so many varieties of rhyolite as that examined by the Fortieth Parallel Survey in North America, where Zirkel finds every type of rhyolitic structure hitherto recognised in other parts of the world, and groups the typical rhyolites into fifteen varieties.

	European Felsite Porphyry.[1]						
	Altendiez, Nassau.	Varese-Lugano.	Blattengrubwies.	Brusin-Arzizie.	Valgana.	Deserto.	Eichhagen, Westphalia.
Silica	68·54	71·55	75·78	79·75	84·10	87·20	76·44
Alumina	9·49	16·60	12·16	12·00	10·50	6·00	12·64
Peroxide of iron	8·60	...	1·77	...	...	...	0·29
Protoxide of iron	3·23	6·40	0·51	1·75	1·10	3·66	0·51
Manganese	trace	...	...	...	trace	trace	...
Lime	0·54	1·60	0·79	2·10	0·04	0·60	...
Magnesia	0·42	0·85	0·25	0·24	0·03	0·08	0·27
Soda	3·14	0·20	1·16	0·20	1·10 (Soda and Potash)	trace	3·41
Potash	5·11	trace	6·28	0·15		trace	4·29
Titanic acid	1·36	...	...	...	...	...	...
Phosphoric acid	trace	...	...	...	...	...	0·19
Water	0·30	2·44	1·39	3·60	1·93	2·30	1·46

Granitic Rhyolite.—The granitic rhyolite, which is always rare, is distinguished by being entirely crystalline. The ground mass of this Nevadite consists of well-defined microscopic grains of quartz and felspar, through which larger crystals are scattered.

Zirkel's Classification of Rhyolites.—We briefly summarise Zirkel's classification of the typical rhyolites. The commonest type presents a microfelsitic structure, sometimes becoming more or less granular, and usually characterised by imperfectly formed sphærolites. It generally contains ferrite and opacite.

A second variety consists chiefly of microfelsite, with some polarising particles and single dark axiolites; or the microfelsite may be traversed by fibrous strings arranged axially, with a distinct middle division; or it may consist of a network of such strings, enclosing radially fibrous and concentric spherolites in its meshes; or the meshes may include more or less distinct aggregations of a crystalline granular

[1] Justus Roth: "Beitrage Petrograph der Pluton." Gesteine, 1873, taf. xiii.–xiv.

character, or the meshes may disappear altogether, leaving simple aggregations of sphærolites, or the meshes may expand into confused aggregations of bunches of parallel fibres; or a felt-like structure may be formed of short confused fibres, or the sphærolites may be mixed with aggregations of cumulites. Other rhyolites consist of aggregations of colourless polarising particles and colourless glass, but these are rare. Alternating bands of microfelsite and light-coloured glass are also rare; but it is commoner to find a half-glassy mass made up of little thin microliths almost passing into obsidian, but containing crystals of quartz, sanidine, and biotite. The homogeneous glass of other rhyolites is sometimes contorted and undulated with dark-brown grains; or spherolites and axiolites may replace the glass, and have fluxion structure marked by similar bands of grains; or the light-coloured homogeneous glass may be traversed by perlitic cracks, and have a fluxion-structure marked by narrow zones of microfelsite on both sides.

Characteristics of Rhyolites.—Rhyolites are best characterised by fluid structure and fibrous aggregates. The wavy fluidal structure is due to several causes. First, coloured bands are formed by parallel layers of needles and grains of ferrite and opacite. Secondly, the different layers of the rock may vary in texture, as when crystalline granular layers alternate with spherolite layers; or when microfelsitic layers alternate with less crystalline layers; or perfectly granular layers with imperfectly granular layers. The corrugations of fluidal structure are also sometimes marked by the alternations of layers of colourless glass with brownish-yellow globulitic glass.

The fibrous concretions of rhyolites comprise four types: first, those in which the fibres radiate from a centre as in spherolites; second, those in which the fibres are arranged longitudinally about an axis forming axiolites; third, those in which the fibres are parallel to each other forming bunches or bundles; and fourthly, those in which the fibres are confusedly mixed. These fibrous aggregates are wanting in trachytes.

Rhyolites are even better characterised by their mineral composition. The crystalline quartz component is a consequence of the high percentage of silica in the rock; being often in excess of what could be used up in forming felspar, some has crystallised separately.

Quartz in Rhyolites.—The quartz of rhyolites may be in fragmentary grains, or in double six-sided pyramids, divided by a six-sided prism, the latter condition being developed in proportion to the crystalline texture of the rock. The glass inclusions sometimes have this crystalline form, and then contain dark bubbles; but the moving bubble and the fixed bubble are never found in the same quartz. The quartz is poor in mineral inclusions, but contains ovoid gas cavities, and ovoid inclusions of colourless glass, in which are opaque needles. Microliths occur, and fluid inclusions have been described in rhyolites from Lipari, Samothrace, the Auvergne, and Kis Sebes, but they are evidently rare; for among all the rhyolites of North America, only two were found with fluid inclusions in the quartz,

and on both, Zirkel expresses doubts as to the grains being originally generated in rhyolite. Tridymite occurs in the ground mass in minute crystals; and it also occurs in well-marked aggregates of hexagonal plates, but is only abundant when the proportion of quartz is small; and it is absent from the glassy varieties of the rock.

Felspar in Rhyolite.—The predominant felspar is sanidine, clear as water, and sometimes in twin crystals of the Carlsbad type. Occasionally lamellæ of plagioclase occur in the sanidine. The felspar is richer in gas cavities than the quartz. The glass inclusions may be either clear or coloured. They are ovoid or many-sided, or ledge-like forms, with angular indentations. Their microliths are isolated, as are the plates of biotite. The felspar in the granitic rhyolite of the Rotorua Lake in New Zealand is opaque.

Plagioclase occurs in small, clear, long, isolated crystals. Their principal cleavage-plane agrees with that of albite and oligoclase. The amount of plagioclase, however, is less than might be expected from the percentage of soda in the analyses, so that soda is probably diffused in the ground mass.

	American Rhyolites.[1]			
	Lassen's Peak, California.	Harlequin Cañon.	Pine Nut Cañon.	Mopung Hills.
Silica . . .	68·84	70·15	75·07	77·00
Alumina . . .	17·73	14·51	11·40	11·54
Peroxide of iron .	...	1·24	0·53	0·69
Protoxide of iron .	3·11	1·20	1·28	0·42
Manganese . .	...	0·11	trace	...
Lime . . .	3·58	1·12	0·61	0·43
Magnesia . . .	0·90	0·27	0·11	trace
Soda . . .	2·89	3·79	1·15	2·45
Potash . . .	3·59	5·60	8·33	6·72
Lithium . . .	trace	trace	trace	trace
			CO_2 trace	
Loss on ignition .	1·50	1·38	1·74	0·77

Mica, Hornblende, and other Constituents in Rhyolite.—The magnesian mica is of a brown tint, rarely green. Its films are often bent by fluxion structure. It frequently occurs in hexagonal plates, which are usually visible, but may be microscopic.

Hornblende is sometimes associated with the mica, sometimes separate. It always occurs in brown plates or needles.

Augite is commonly seen in small grains or microscopic crystals, but in some of the American rhyolites the ground mass is an almost wholly crystalline aggregate of comparatively large grains of felspathic quartz and augite.

Contrary to an otherwise general rule, augite in these rocks is

[1] U. S. Geol. Surv., Fortieth Parallel, vol. i. p. 652; Table XI.

associated with quartz. Like the hornblende, it is usually associated with magnetite. Apatite and magnetite are diffused in many rhyolites, but both are sometimes absent. There are few, if any, accessory minerals in rhyolite, and when found they are always integral parts of the ground mass.

North American Rhyolites.—Rhyolite is the predominant superficial volcanic rock of the Fortieth Parallel, where its oldest eruptions appear to date from the beginning of the Pliocene period. It accompanies the trachyte in the Rocky Mountains, but there are no important exposures between the Rocky Mountains and the western side of the great Salt Lake Desert. Between the 114th meridian and the borders of California, rhyolites are widely spread. Many of the exposures occur at the angles of great flexures of the rocks. Against the base of Mount Richthofen rhyolites are poured out in immense streams. Here their colour is dark, and the ground mass is a fine-grained mixture of broken crystals of sanidine and dark quartz, in which are contained large clear grains of quartz, shining black hornblende, and large fractured sanidine; but besides the sanidine, in some localities orthoclase crystals are found, but then the rock has a more felsitic character, and the ground mass is usually light. The rhyolite of Desert Buttes is sometimes warm grey, sometimes salmon colour, and contains spherolites and lithophyses, and is reticulated by veins of translucent chalcedony. At times the rhyolites are glasses, variously banded and tinted, containing sanidine and quartz.

In the region of the Washoe Mountains, to the south-west of Salt Lake Desert, rhyolites are grandly spread, presenting excellent examples of viscous flow, and of variations in rock structure, sometimes being green and compact, like hornstone, at other times brick-red and porphyritic, with sanidine and prisms of hornblende.

North of Spring Cañon the rhyolites include pumice, and brilliantly tinted glassy and half-glassy rocks, the quartz in which has inclusions with moving bubbles. At Clover Peak the rock is as black as basalt, and free quartz has a brilliant olive-green tint. The tuffs of this region are sometimes creamy or light-grey in colour, sometimes pale-green or olive-tinted. The rhyolites of the Sierra Nevada are among the most important in the world. They form the Augusta, Fish Creek, Shoshone, Toyabe, Cortes, Seetoya, and part of the Pinon ranges, and the Mallard Hills. This belt was explored for a length of 200 miles and a breadth of 40 to 80 miles.

North of the Humboldt River at Osino Cañon, the rock is rich in crystalline constituents, and contains sanidine, biotite, and quartz. Biotite is also met with in the ground mass of rhyolite in other localities, but is usually rare. In Pinon Pass there is more black mica than in any other exposure. In the Shoshone Mesa the rock presents several varieties besides the ordinary type, with sanidine, cracked quartz, a little plagioclase, and occasional mica. One of these is pearl grey, rich in tridymite, and poor in crystalline secretions. Others are dark pearlites, with more or less augite, and characterised by spherolitic concretions. In several localities, as at Cortes Peak,

breccias are seen, and in Owhee Bluffs pink and red angular fragments are embedded in the thin lava streams like pieces of inlaid wood. At New Pass, in the Desatoya Mountains, the rhyolites are not less than 1000 feet thick. The breccias in this pass are white and green below, and pink and red above. The sanidine, found in a porphyritic rhyolite on the west, has a play of colour like labradorite, and sanidine with this property is also found in the Pahute and Augusta Mountains. It is noticed that the soda in this sanidine is almost equal to the potash. At Antimony Cañon the rhyolites are 6000 feet thick, and throughout the region of the Augusta and Fish Creek Mountains the whole country is covered with rhyolite to the thickness of from 2000 to 7000 feet, and this exposure is nearly 100 miles long, by from 12 to 20 miles wide; but the character of the rock seems to have changed a little with each successive outpouring. On the eastern base of Pahute range, the rhyolite is a minutely microfelsitic rock, approaching the texture of porcelain, and has few minerals that can be recognised by the naked eye. In Bayless Cañon, in the southern end of the Montezuma range, is a ridge of rhyolite a mile long, and 300 to 400 feet high, made up of well-developed prismatic columns, varying from an inch to two feet in diameter. In almost every district the colour is very variable, and frequently passes through such tints as white, pale green, pale lilac, bright indian red, deep purple, and olive brown. Its laminated structure is often marked by bands of colour as fine as the leaves of a book, though it is as frequently structureless; and in mineral composition it presents as wide a range as any known rock. Tertiary rhyolite is never covered by any lava except basalt.

Augite Andesite.

Augite andesite is essentially a combination of augite with plagioclase, and is free from olivine. This absence of olivine is held by Rosenbusch to similarly characterise diabase, and to distinguish that rock from basalt and melaphyre. These rocks further differ from basalts in frequently containing hornblende and biotite, and the quantity of augite is less than in basalts. The ground mass may be crystallised or glassy, and occasionally shows fluidal structure. The characteristic crystals in it are oligoclase and augite.

The percentage of silica ranges from 55 to 60. Occasionally there is a little quartz, which rarely occurs in basalt as an original element. The silica more frequently is used up in the formation of sanidine, which sometimes may make up as much as one-half of the felspar, though the quantity is usually subordinate. Magnetite and apatite are always found, and in a few localities tridymite occurs. The chief products of decomposition in augite andesites, are chlorite, iron oxide, calcite, opal, and chalcedony.

The plagioclase is found in rod-shaped crystals, but the larger forms become twins. The felspar is often more or less replaced, and is converted into opal in the augite andesites of Hungary. The

sanidine is only to be recognised by its crystalline form and optical properties. Bastite is a product of the decomposition of enstatite. Augite, like the plagioclase, contains inclusions of glass, but they rarely show devitrification as in the felspar; they are similarly associated with steam pores, microliths, and occasional fluid inclusions. Olivine and plates of mica are very rarely detected in the ground mass.

Quartz Augite Andesite.—Zirkel divides augite andesites into two groups according to the presence or absence of quartz. Most of the andesite from the American Andes belongs to the quartz-bearing variety, and contains from 57 to 67 per cent. of silica. It is recorded, among other localities, as from Chimborazo, at a height of 17,916 feet, Guagapichincha, Cotopaxi, Antisana, Riobamba, Tunguragua. At Palissade Cañon in the Cortez range, in the region of the Fortieth Parallel Survey, an exceptional rock of this kind occurs with 62 per cent. of silica, which has a granular crystalline texture, is free from glass, abounds in well-crystallised quartz, has no hornblende or olivine, and but little sanidine, and consists chiefly of plagioclase, with some augite and brown mica.

Distribution of Augite Andesite in Europe.—The variety of augite andesite which is free from quartz is found chiefly in lava streams; it is seen in Iceland, at Hals, in the Hecla lava of 1845, though the ashes of that eruption differ in chemical composition. It occurs at Portillo in Teneriffe, at Serra Varalau, in the Val del Bove. It forms much of the volcanic summit of Radicofani in Tuscany, where it contains olivine. The augite andesite of Reykjavik is of a greyish or reddish colour, and consists of oligoclase, augite, and olivine, with a felspar in loosely-connected thin plates. The rock which caps the Löwenburg in the Siebengebirge appears to contain nepheline, and is grouped by Zirkel as an augite andesite. The Transylvanian augite andesites have a crystalline ground mass at Nagy Banya, but generally the ground mass varies from a microcrystalline to a microlithic state, with the remains of a more or less glassy base; and many varieties of texture occur in these rocks at Tokaj, Schemnitz, and other localities in Hungary. A black variety of the rock with a resinous lustre occurs at Bagonya in Hungary. In the Auvergne, augite andesites composed the lava-flows which ran down from the Petit Puy de Dôme, Parion, and from the Puy de la Nugère towards Volvic, where they become crystalline. Augite andesites are well developed in Santorin in the lavas of 1865.

The South American augite andesites from Tunguragua, Cotopaxi, and Antisana, though containing 63 to 67 per cent. of silica, contain no quartz, but are rich in brown glass.

North American Augite Andesites.—To the south-west of Salt Lake, where an angular bend occurs, near the southern extremity of the Cedar Mountains, is an outburst of andesite which occupies the entire angle. In external appearance it is quite like basalt; it occurs in thin sheets, and often shows rude columnar joints. Where broken it shows a large amount of pale grey glass, with crystals of plagioclase,

augite, and a little hornblende, with some brown biotite. The augite always predominates over the hornblende. Occasionally, as at the mouth of Spring Cañon, this andesite contains a little sanidine. In Melrose Mountain biotite predominates, so that the rock might be termed a mica andesite; but Clarence King regards it as evidently comparable to the rock of Spring Cañon, with which it may have been originally continuous. In Egyptian Cañon this rock exhibits a columnar structure; but Clarence King describes the columns as cylindroids rather than prisms. Sometimes considerable quantities of apatite are seen under the microscope. It is difficult to draw a distinction between this rock when free from hornblende, and basalts which are free from olivine. It is also seen on the eastern side of the Cortez range, north of Jacobsville, on the Reese river, and in many other localities. The crystals vary much in size, and frequently contain both in the augite and plagioclase yellow or brown glass inclusions. The rock is commonly covered by rhyolite, but occasionally, as in the Reese river, by basalt. The augite andesite of Augusta Cañon is overlaid by trachyte, and it is on this account that the American geologists have grouped it rather with the andesites than with the basalts.

In the Fortieth Parallel District it occurs to the west of Basalt Creek in Washoe, where it is a resinous brownish black rock with ledge-shaped felspar crystals, and shows under the microscope a brownish-yellow glass ground mass. It abounds in yellowish green augite with colourless felspar microliths, and black grains of magnetite, with larger crystals of augite, sanidine, and plagioclase. Like nearly all the known rocks of the same class, it contains 58 per cent. of silica. Other augite andesites occur in the hill to the west of Steamboat Valley, Nevada. In a ravine north of the Truckee Road, by the Truckee river, the augite is green, and the rock contains half-decomposed olivine with abundance of sanidine. Besides these exceptional augite andesites, typical types of the rock occur in the Foot Hills south of Wadsworth, near the Truckee river. The felspars are remarkable for the quantity of their inclusions, which are chiefly kernels of ground mass. Pale-yellow sections of augite occur with light-brown hornblende, surrounded by a narrow black border. Similar rocks are found in Augusta Cañon, Augusta Mountains, and similarly free from olivine. Sometimes there is very little sanidine; but at Susan Creek Cañon, Nevada, the augite is so full of glass inclusions, that upwards of seven millions would occur in a cubic millimeter. Augite andesite is found in the Foot Hills of the Cortez range, in Independence Valley, Nevada, and in Waggon Cañon. In the rocks to the west of White Rock, Cedar Mountain, the augite andesite contains some brown biotite. In the eastern portion of the Fortieth Parallel Territory, these rocks have a pale grey glass base, while in the western territory the glass base is brownish.

Augite andesite occurs in the Palau Islands, at Kyneton in Victoria, Australia, and in Java.

Basalt.

Basalt, anamesite, and dolerite, are typical basaltic rocks, which vary in texture from the compact condition of black biscuit china seen in basalt, to a finely granular state in dolerite. These lavas have a dark colour on the newly-fractured surface, varying through shades of greyish brown, blue, and greenish black; but where the external surface is weathered, the rock is commonly a pale drab, though the tint varies with chemical and mineral composition and texture. Basaltic rocks have a high specific gravity and basic composition. Their silica rarely sinks below 40 per cent.; a lower percentage of silica is usually associated with large percentages of iron, and sometimes of lime. The silica rarely exceeds 56 per cent. The alumina has no necessary relation to the silica, though the average amount ranges between 11 per cent. and 28 per cent. The lime, magnesia, potash, and soda all vary in amount, and on this variation depends the mineral composition of the rock. Basalt abounds in labradorite and augite, generally contains magnetite and olivine, and sometimes may have a little quartz and sanidine.

	Basalt.						
	Kreuzberg in the Rhön.	Bärenstein Erzgebirge.	Kreuzberg, Silesia.	Geiselstein, Hesse.	Dolerite Lava from Ætna.	Dolerite Lava of 1652 from S. Miguel, Azores.	Lamlash Tachylyte, Arran.
Silica	36·68	42·64	44·85	46·32	49·27	51·4	56·05
Alumina	14·34	17·11	17·56	11·86	18·54	14·0	17·13
Peroxide of iron	22·30	5·29	...	4·50	6·98	...	10·30
Protoxide of iron	...	4·80	13·75	7·26	5·62	8·1	...
Manganese	...	0·45	1·32	0·14	...	...	trace
Lime	15·59	14·58	12·83	10.43	10·38	12·0	6·66
Magnesia	9·18	7·34	9·74	11·82	3·76	7·1	1·52
Soda	0·77	1·38	0·90	2·10	2·22	3·6	0·98
Potash	3·93	3·43	0·24	4·09	3·45	3·8	3·29
Water	...	2·35	0·60	1·75	...	...	3·50

Zirkel's Classification of Basalt.—Zirkel distinguished several varieties of basalt according to the texture of the rock, which is sometimes even-grained, and free from ground mass and porphyritic crystals; or it may be very fine-grained with porphyritic crystals, and only a trace of glass; or there may be a homogeneous glassy or half-glassy ground mass half-filled with crystals; or there may be large crystals in an ill-defined amorphous mass.

But besides these varieties of texture due to conditions of cooling, almost every locality affords varieties distinguished by mineral composition; and sometimes this variation is so marked that the felspar

basalt may have its felspar more or less absolutely replaced by nepheline, or by leucite, so as to be conveniently distinguished as nepheline basalt or leucite basalt. The former is not necessarily free from felspar, and may contain a little leucite; the latter may include nepheline with leucite, but rarely felspar.

The felspar basalts are more characteristic of Western Europe; the leucite and nepheline basalts are typical of the Erzgebirge, Eifel, and Italy.

Felspar Basalts.—Most basalts are felspar basalts; the plagioclase cannot be determined with certainty, though there is rarely any doubt that it is labradorite. It occurs in long prismatic crystals, which are the predominate constituent of the rock, and cross each other in various directions. They show with polarised light the coloured striæ indicative of laminated twin structure, and occasionally two sides of the crystal show blue and yellow colours.

If the lamination is absent, the felspar is identified as orthoclase, as in the dolerite of Rowley in Staffordshire, where clear structureless glassy felspar also occurs.[1]

Felspars often include augite, magnetite, and apatite. The felspar is sometimes partly decomposed, when the interior of the crystal is turbid, or a little chlorite occurs in it; and pseudomorphs of felspar in chlorite are found at Mugdock Tunnel, near Glasgow; Craigie Hill, near Edinburgh; Deep More in Staffordshire, and Matlock in Derbyshire.

Pseudomorphs are easily recognised under the microscope, because the optic axes vary in every part of the crystal, so as to produce a play of colours in all positions of the prisms.

Augite is usually found in well-formed crystals, which have a brownish tinge, and show bright colours in polarised light. It gives an eight-sided section, while hornblende occurs in six-sided crystals. In polarised light, augite, as a rule, shows no change of colour, though in the rock at the Necropolis Hill, Glasgow, it is slightly dichroic, and shows a purple tinge. Hornblende is always dichroic, and as the polariser is rotated the colour changes from yellow to brown. Twin crystals of augite are common, and laminated crystals are found at Bowling, near Dumbarton. Minute grains of magnetite occur in augite crystals; and in the Campsie Hills, near Glasgow, the mineral contains cavities in lines parallel to the sides. When augite decomposes it yields a grey fibrous substance, or a turbid granular substance, and is often more or less perfectly replaced by chlorite. When hornblende is present it may be brown or black, and is distinguished from the augite by its shining fracture, as at Mayen in the Eifel, many places in the Westerwald, at Schima and Kostenblatt in Bohemia, and in Heilenberg and Gickelsberg in Saxony.

Olivine is one of the more conspicuous minerals in basalt, often forming glassy oil-green grains like drops. At Dalsmynni much of the ground mass of the basalt is formed of grains of olivine; at Unkel on the Rhine, and occasionally in the Auvergne, the olivine crystals

[1] See Allport: Carbon. Doler., Q. J. G. S., vol. xxx.

vary in size from a diameter of half an inch to four inches. Near Wiesbaden similar masses of olivine reach a diameter of two feet. In Bohemia the olivine is usually well crystallised. It is generally present in the dolerites of Scotland, but in the North of Ireland and in Iceland there is rarely any trace of olivine, though it is sometimes abundant in definite bands. In polarised light it shows brilliant red and green colours; it never contains any mineral except magnetite, but often includes glass cavities. In England olivine is usually more or less altered; and in the midland counties it is always changed into a green substance like serpentine. The alteration begins at the surface of the crystal and extends inward along fine cracks. Serpentinous pseudomorphs are seen in the dolerite of the Clee Hills, of Little Wenlock, Matlock, and Rowley. Olivine is partly converted into hematite in the basalt of Duncarnock in Lanarkshire, and at Bowling, near Dumbarton. It is replaced by calcite in the South Staffordshire Coalfield, and is sometimes replaced by zeolites.

Bronzite is found in the basalt at Oberwinter on the Rhine, and in the Lohrberg in the Siebengebirge. Iron pyrites and blende are both found in the basalt of Unkel.

In Antrim and some other localities native iron is found in small particles; and at Ovifak in Greenland, nickel-bearing iron is plentiful in basalt, and sometimes occurs in very large masses. Titaniferous iron is often found in the Rhine basalts in large visible grains.

Magnetite is invariably present in British basalts, and, being in octahedrons, shows as an opaque black square, but it is sometimes so clustered that the form cannot be recognised. Specular iron is recognised by its blood-red colour, and occurs in thin hexagonal plates.

Brown mica is present, in some Scotch dolerites, in irregular polygonal plates or strips. In sections parallel to the cleavage plane, biotite is not dichroic, and is always dark between crossed nicols. Sections at right angles to the cleavage plane vary from pale to very dark-brown when the polariser is rotated. Mica is seen in the basalt at Veitskopf, at Krüfter Ofen, and the Laacher See, and has been noticed near Teplitz and Bilin in Bohemia.

Apatite is always present in British dolerites in slender hexagonal needles; it is very common in the felspar and augite, and never encloses any mineral except magnetite.

Quartz and sanidine have been detected in many localities in North America; and in Europe are found in the basalts of the Siebengebirge.

The percentage of water varies from $7\frac{1}{2}$ per cent. in basalts which are rich in zeolites, to nothing in those which are free from zeolites. When the basalt contains nepheline, decomposition of that mineral yields natrolite; but most zeolites in basalt are due to the decomposition of labradorite.

Agates and chalcedony often fill steam cavities in vesicular basalt.

The glassy matrix, when present, is seen to be a structureless substance, filling the interstices between crystals. Its structure is sometimes felsitic or even cryptocrystalline. When felsitic it always

shows double refraction. It often has a granular aspect, but its texture is due to consolidation during incipient crystallisation. Felsitic texture is well seen at Inch Knock, near Coatbridge in Lanarkshire, and in Kaimes Hill and Dalmahoy Hill, near Edinburgh.

The glassy base is often more or less altered. At first a fine grey dust appears in it, and with further change the glass may be replaced by specular iron, chlorite, calcite, and quartz. Grains of quartz, clear and crystalline, of secondary origin, are common in Scotch dolerites.

Representatives of Dolerite in Time.—Mr. Allport, in 1874, urged that the names of greenstone, melaphyre, and diabase should be discarded, since they are essentially synonyms for basaltic rocks. Melaphyre is only a dolerite of carboniferous age; and diabase is a dolerite which is so far decomposed that the mineral chlorite is diffused in it. And as the oldest rocks are most altered, it results that most diabases are of Cambrian, Silurian, and Devonian age;[1] they are basalts modified by the action of infiltrating water. Hence, accepting these views, we give no detailed account of the rocks so named.

Modes of Occurrence of Basalt.—Basalt forms lava streams which may be traced to their connection with the parent cone in many of the Tertiary volcanoes of the Inner Hebrides, the Auvergne and the Eifel. Interstratified sheets of basalt are characteristic of the British Carboniferous, Devonian, and older Primary rocks. In the form of dykes, however, basalt has a much wider geological horizon, being intrusive in almost every kind of plutonic, metamorphic, and sedimentary rock, and in all periods of time.

Contemporary basalt is absent from the secondary rocks in England, but occurs in Germany, developing prismatic structure in the triassic sandstones which it covers; while in the jurassic rocks near Dettingen, basalts are accompanied by massive tuffs and agglomerates. Basalt induces a columnar structure in the Quadersandstein, near Kribitz and Zittau.

Difference between Basalt and Augite Andesite.—The difference between basalt and augite andesite consists essentially in the presence of olivine, for it is only when olivine is present that the rock can be classed as basalt. The percentage of oligoclase may undergo any amount of variation; andesine and anorthite may both be associated with the labradorite; and when sanidine occurs it is commonly in twin crystals.

Tachylyte.—The glassy form of basalt called tachylyte is very rare in this country, and has only been described at the edges of basalt dykes, where the rock has a lustrous pitchy aspect, with extremely minute columnar structure and a dark-brown base, full of cumulites which are regarded as the embryos of magnetic crystals, though well-formed crystals of basalt minerals are scattered through the dark-brown glass. Professor Judd has met with this rock at Screpidale in the east of Raasay, at Beal in Skye, at Sorne north-west

[1] Allport: Carbon. Dolerites, Q. J. G. S., vol. xxx.

of Mull, and Gribun west of Mull, and east of the Treshnish Islands, and opposite Lamlash in the Holy Island, east of Arran.

In some continental localities trachylyte is spherulitic, as at Bobenhausen, and it is perlitic at Marostica near Bassano.[1]

Geographical Distribution of Basalt.—The large areas occupied by basalt can only be adequately appreciated with the aid of a geological map. They occupy a great space in the southern Eifel; there is a larger district in the Westerwald, and immense spreads in the Vogelsberg, the Rhön, Mittelgebirge, and other parts of northern Bohemia. Smaller exhibitions are seen in the Oelberg, in Petersberg, and the Nonnenstromberg in the Siebengebirge, at Unkel, at Scheidsberg, near Remagen; the Landskron, near Neuenahr; Steinheim, near Hanau; Wenneberg in Ries, Kemnath in the Fichtelgebirge, Gröditzberg and Striegau in Silesia, Suhl in the Thüringerwald; and many places in Saxony, Bohemia, Moravia, Styria, Hungary, and Transylvania. In North Italy basalts occur at Fonte del Capo, near Avesa; Vestena Nuova, south of Monte Bolca; Radicofani, in Tuscany; and among the lavas of Etna. In the Auvergne, basalts are seen at Mont Rognon, the Plateau of Cozent, the Plateau of Prudelles, the Puy de Charade, Puy de Côme, Puy de Colière, and the lavas of Gravenoire. There are a few localities for basalt in the extreme south of Sweden, such as Sösdala and Höör. Basalts are well known in Greenland, at Ovifak in Iceland, the Faroe Isles, and Inner Hebrides; at Paranagua in Venezuela, in the Galapagos Islands, in the Sandwich Islands, north of Melbourne in Victoria, St. Helena, the Isle of Réunion, at Funchal in Madeira, at Palma, and at Cruz in Teneriffe.

Types of Basalt in North America.—The basalts of the Fortieth Parallel belong to two types. In the Elkhead region, and the Kawsoh Mountains in Western Nevada, these rocks are nepheline-basalt; but in all other localities there is no trace of nepheline, and the rocks are felspar basalts. The latter rock usually consists of plagioclase, augite, and olivine; but on the upper Snake River it is composed of quartz, plagioclase, augite, and magnetite, without any olivine, so that it makes a transition to the neighbouring augite-bearing quartz trachyte; but the ground mass is free from quartz. South of the Yampa River, hauyine occurs as an inclusion in colourless crystals of plagioclase.

The nepheline basalt in the Elk Mountains is light grey and very porous. In the fine ground mass the eye distinguishes augite and olivine; while the microscope shows biotite, magnetite, nepheline, plagioclase, and göthite. A dyke called the Rampart, only six feet wide, rises to a height of 30 to 60 feet, and extends for four or five miles. It is formed of basaltic columns arranged horizontally. It is

[1] Hyalomelane was defined as distinguished from tachylyte, by not forming a gelatinous-silica with acids. But Professor Judd and Mr. Grenville Cole give strong reasons for rejecting the term. The rock occurs in Germany, at Ostheim in the Witterau, and at Sahaburg in the Reinhardswald. A similar rock occurs in the Ruby Valley range, in the Fortieth Parallel Region, U. S. A.

free from triclinic felspar, is rich in biotite, and shows augite, nepheline, and sanidine. Sometimes triclinic felspar is present with nepheline, as at Hantz Peak and Fortification Peak.

	American Basalts.[1]		
	Summit of Elk-head.	Stony Point Range.	Ombe Range, Nevada.
Silica	48·60	48·40	54·80
Alumina	15·78	17·95	17·58
Peroxide of iron	3·22	·2·28	0·97
Protoxide of iron	7·21	8·85	8·84
Manganese	...	trace	trace
Lime	8·34	10·05	8·22
Magnesia	10·13	6·99	4·47
Soda	3·77	2·86	3·14
Potash	1·65	1·03	1·16
		TiO^2 0·24	
	trace PO^5 0·11	trace CO^2 0·84	...
Loss on ignition	1·30	0·34	0·94

Modes of Occurrence of American Basalt.—There is frequently evidence that the basalt was extremely liquid, and flowed for long distances, spreading out in thin sheets, which are superimposed on each other. Felspar basalt extends over hundreds of miles in Northern California, Oregon, and Idaho, and the surface of the country appears to be made up of continuous sheets.

In the Fish Creek Mountains basalt is seen to have come to the surface through true craters, in the rhyolitic cones. This rock contains large crystals of sanidine an inch long, and its base cannot be resolved into its constituent minerals.

In most cases the basalt appears to have been poured out from fissure eruptions, as in the Pahute range. The sheets, frequently 1000 feet thick, are exposed on table-lands; while in some cañons, like those of Clarke's Station, the thickness amounts to 2000 or even 3000 feet.

The degree to which the rock is crystallised and the minerals developed in it vary much with locality. In the Rugby chain, basalt breaks with a curved fracture, and rings like bottle-glass, and is a dark-brown glass, which is representative of obsidian, though the glassy conditions are less developed than in the island of Hawaii. After crystals of felspar, augite, and olivine have formed, the amount of glass which remains is very variable; and the basalts of the hills to the north of Sou Springs have the whole of the ground mass crystallised, and are remarkable for absence of glassy material. On

[1] U. S. Geol. Surv. Fortieth Parallel, p. 676; Table XII.

Shoshone Mesa the basalt contains quartz, and occasionally augite is deficient or almost wanting. The olivine crystals are often so abundant as to give a cleavage to the rock. Occasionally they form nearly the whole ground mass, and the crystals often contain an abundance of picotite.

On the south of Black Rock Mountain, in Mud Lake Desert, is a coarse dolerite in which the plagioclase crystals are an inch long, and the augite crystals a fourth of an inch in diameter. The ground mass of this rock is slightly vitreous.

Aspect of Basaltic Rocks.—In colour basalt may be black, chocolate, dark grey, or greenish, but the latter colour is always due to abundance of olivine. It frequently exhibits horizontal columnar structure indicative of having cooled in dykes. It sometimes occupies eroded valleys in the older rhyolite. Where decomposed, the basalt is charged with seladonite and chalcedony. It shows all stages of texture, from compact crystalline, through porous, to highly vesicular and scoriaceous rocks as light as a sponge. Basaltic tuffs are met with, and sometimes form an earthy and sometimes a true pelagonite. Even those which are compact vary in texture; some basalts are evenly granular and poor in glass, like the common British types. Others have a ground mass formed of a very fine crystalline aggregate of microliths of felspar and augite, with larger crystals of felspar and olivine, and occasionally of augite also. A third type is a homogeneous yellowish-brown glass half filled with crystals, while sometimes the basalt is a mixture of small and large crystals, with wedge-shaped masses of globulitic glass between the crystals, and is then regarded as closely related to augite andesite. Many of the American basalts closely approximate to those of Europe. The basalt near American Flat Creek in Washoe, like that of Schemnitz in Hungary, has no glassy base, and consists of an aggregate of fine-grained, pale-coloured augite and black magnetite, with macroscopical and large microscopical crystals of plagioclase and sanidine, often with olivine. But the minerals undergo considerable change with the locality. East of Spanish Spring Station, in the Virginia range, the augite is green. Near Wadsworth the plagioclase includes augite and olivine. The olivine itself often contains octagonal crystals of picotite, a variety of chrome spinel, also found in the basalts of Germany, Bohemia, Hungary, and Italy. The nepheline basalts contain tridymite and sanidine. On the Upper Little Snake river grains of quartz occur surrounded by augite.

Leucite Basalt.

Leucite basalts consist of augite and leucite. Mica occurs in microscopic films in the fine-grained ground mass which contains porphyritic crystals of augite, and usually olivine. The rock is very rarely glassy, though a glassy condition is seen in the magma of the Vesuvian lavas of 1822 and 1858. The basalt of Schackau in the Rhön Mountains is particularly rich in leucite. On both slopes of the Erzgebirge the basalt consists chiefly of leucite, augite, and

nepheline, though in some cases the quantity of nepheline is less than in others. In a few localities olivine is added, and sometimes Humboldtilite. This rock is well seen at Pohlberg, near Annaberg. In the eastern Mittelgebirge, leucite-basalt occasionally contains a little felspar, probably sanidine, and abounds in trichites. Near Aussig the felspar is much more developed, and at Rothweil, in the Kaiserstuhl in Baden, the quantity of leucite is diminished, so that it is not always seen in hand specimens. At Stoffelskuppe in the Thüringerwald, the leucite-basalt is free from felspar, and at Westberg, near Hofgeismar, it is rich in large crystals of nepheline. In the Eifel, the basaltic lavas contain leucite in many places, especially near Wehr on the Laacher See, Veitskopf, the Forstberg, Bürresheim, near St. Johann. Other localities are Uedersdorf, Wehrbusch near Daun, and Birresborn and Gerolstein.

	Leucite Basalt.			
	Capo di Bone, Nepheline-Leucitophyre.	Granatello, Vesuvius Eruption, 1631.	Boccamonfina.	Niedermendig.
Silica	45·93	48·03	52·08	47·48
Alumina	18·72	20·78	17·30	21·26
Peroxide of iron	...	4·72	...	12·39
Protoxide of iron	10·68	3·27	6·52	...
Manganese	...	trace	...	...
Lime	10·57	10·18	12·23	8·54
Magnesia	5·67	1·16	1·25	3·16
Soda	6·83	7·12	9·63	2·39
Potash	1·68	3·65		3·42
Water	...	...	...	...
Loss	0·59	0·17	0·59	0·35

The famous porous basalt of Niedermendig, worked for millstones and paving-stone, contains leucite and nepheline, with augite, hauyine, and olivine, with triclinic felspar in some specimens. Chemically, these rocks may be compared with Malvern schists and shales.

Leucite Basalts of North America.—In North America this rock is found in the Leucite Hills of Wyoming. The American leucite rocks are yellowish grey and finely porous, and contain brownish mica in long stripes peculiar to the rock. Leucite crystals are microscopic, but abundant beyond anything known in European rocks. The crystals are too small to show the twin structure indicated by alternating dark and polarising bands. The rock contains pale-green prisms and needles, which are referable to augite. There is a small quantity of magnetite, and a few comparatively thick crystals of apatite. The colour of the European leucite rocks is darker, because the augite

crystals are larger and more abundant, and there is more magnetite. There is an entire absence of felspar in the American rock.[1]

	Schists and Shales, Malvern.[2]				
	Schist.	Schist.	Shale.	Shale.	Shale.
Silica	43·61	45·82	49·37	53·97	64·37
Alumina	19·34	16·39	21·47	23·24	18·62
Oxide of iron	17·02	16·20	13·39	9·51	2·07
Manganese	0·15	0·45	0·30	...	...
Lime	2·31	1·46	0·75	1·58	1·7
Magnesia	7·10	7·81	1·00	3·66	0·77
Akalies and loss	4·96	5·68	7·06	8·04	8·86
Loss on ignition	5·51	6·19	6·66	...	3·84

Nepheline-Basalt.

Nepheline-basalts consist typically of nepheline, augite, magnetic iron, and olivine. Some varieties contain triclinic-felspar and a little leucite, the latter being more often found. Biotite and Humboldtilite are sometimes met with. Usually the structure is granular, with a certain amount of glassy base; the porphyritic condition is comparatively rare. Good types of the rock occur at Pflasterkaute in the Thüringerwald, and Kohlback, near Bayreuth, in the Western Erzgebirge, near Adorf. Between Joachimsthal and Platten a rock occurs with more augite than nepheline. Nepheline-basalts are found in the Mittelgebirge, and at Kaltennordheim in the Rhön, where the nepheline is recognised by its six-sided section, and is associated with triclinic felspar. In the Swabian Alps the nepheline-basalt is altered, chiefly by the decomposition of the nepheline. The nepheline-dolerite of Katzenbuckel, near Eberbach, in the Odenwald, contains large crystals of nepheline, which are sometimes altered. They lie in a ground mass, rich in green augite microliths, small crystals of nepheline and nosean, magnetic iron, and a little glass. A rock of this character is found at Oberbergen in the Kaiserstuhl. It contains green or brown augite, nosean, nepheline often penetrated by microliths of green augite, with sanidine and garnet penetrated by apatite. Some lavas of the Eifel are characterised by a predominance of nepheline, which is associated with Humboldtilite. Such a rock is seen at Hannebacher Ley, north of the Laacher See: in addition to these minerals, it contains well-crystallised augite, magnetic iron, and a very little leucite. At the Scharteberge, near Kirchweiler, the rock is a compound of nepheline, Humboldtilite, and augite, with hauyine, olivine, and magnetic iron. A similar rock forms the Mosenberg, and occurs near Bertrich by the Moselle.

[1] For further details see Zirkel, Basaltgesteine; Zirkel, Microg. Petrog.; Rosenbusch, Micro. Physiog.; Clarence King, Report Fortieth Parallel, vol. i.
[2] Timins, Q. J. G. S. vol. xxiii., p. 357.

Influence of the Magnesia in Basalts on the Production of Dolomite.

Leopold Von Buch,[1] by a survey of the southern flank of the Alps, was led to believe (1) that the elevation of the eastern range of the Alps, since the tertiary epoch, was contemporaneous with and dependent on the eruption of the basaltic rock termed melaphyre; (2) that the dolomites of the Alps were produced from ordinary limestone at the same time and with the same dependence. The line of dolomites and melaphyres extends (interruptedly) from Bleiberg to Lake Lugano; but the presence of dolomitic limestone in other situations than where melaphyre shows itself, must render inconclusive the inferences drawn from their association in the Alps. At Lugano it is rather *near* the augitic rock than in contact with it, that the limestone is dolomitised. Between the dolomite and melaphyre of the peninsula of Lugano, mica schist and porphyry intervene; and on Monte Argentera, the limestone which lies upon the melaphyre is not dolomitised. De Beaumont observes that it is even rare to find the dolomites near Lugano in actual contact with melaphyre.

Von Buch assumes, it is to gaseous eruptions accompanying the basaltic eruption, that we must ascribe the alteration. But we might with more reason attribute the change to the influence of waters charged with magnesia, liberated during denundation from the decay of augite in long periods of time.

Peridotite.

Rosenbusch includes pikrite, Lherzolite, olivine-rock, eulysite, and Dunite under the name peridotite.

Pikrite is usually a combination of olivine and augite, and is often more or less altered into serpentine; and according to the amount of change depends the development of magnetite at the expense of picotite, which is embedded in the olivine. The olivine is sometimes embedded in the augite. The rock approximates to those varieties of olivine-dolerite in which there are few crystals of plagioclase. The augite frequently decomposes into a fibrous chloritic mineral. In the Fichtelgebirge, where pikrites occur in many localities, titaniferous iron is common, but in the pikrites of the Rhenish Uebergangsgebirge it is replaced by magnetite. Hornblende and biotite occur as accessory minerals.

Olivine-Diallage Pikrite.—Another rock of this group consists of olivine and diallage, and may be compared to an olivine-gabbro from which the felspar has disappeared. It may include magnetic iron, titanic iron, and chromic iron, and as accessories, hornblende and magnesia-mica. This rock is usually more or less converted into serpentine. It is well seen between Bensheim and Darmstadt.

At Schriesheim, near Heidelberg in the Odenwald, the pikrite is a mixture of olivine, hornblende, and some plagioclase, with a little

[1] Ann. des Sci. Nat., tom. xviii. pl. vii.

biotite. Serpentites derived from this rock are found in Elba, and at Monte Ferrato in Tuscany. In Elba the rock is very rich in olivine, while in the Tuscan localities it is subordinate to the diallage.

Eulysite is a similar rock, and may be described as an olivine-diallage with accessory garnet. The Bohemian garnets are derived from this rock. It is sometimes converted into serpentine.

The garnet-olivine rock of Mohsdorf in Saxony is not to be separated as a distinct rock, though the garnet is sometimes wanting, and then the rock is a compound of olivine and diallage.

Olivine-Enstatite consists of olivine, rhombic pyroxene, enstatite, bronzite or hypersthene, and always contains magnetite or chromite. It is seen in Russdorf in Saxony. A hornblendic variety occurs at Crube Varallo in the Monte Rosa district, and a variety rich in garnet is found near Heiersdorf in Saxony, where the rock also contains zircon. Several examples of bronzite serpentines are iue to the decomposition of olivine-enstatite.

Lherzolite, according to Professor Bonney, is a crystalline aggregate of olivine, enstatite, and diopside with some picotite. Its texture is granular, and the grain may be either fine or coarse. It occurs around the small tarn of Lherz, in the Eastern Pyrenees, in the department of Arriège. It is a tough rock of olive-green colour, with olivine for the predominant mineral; it contains emerald-green spots of diopside, dull waxy green spots of serpentine, resinous-looking grains of enstatite, and minute black grains of picotite. The exterior weathers to a bright yellowish or a rusty brown. There are seven exposures in the district, all intrusive in the Lias. Under the microscope olivine is seen in roundish grains, showing between crossed nicols, colours varying from greenish yellow to yellowish green, and from a bright pink to a purple pink. The enstatite is in irregular or long grains; it is colourless in ordinary light, but in polarised light varies from pale yellow or grey to some tint of blue. The diopside rarely occurs in distinct crystals. In polarised light the colours are less clear than those of olivine, and usually vary from rich yellowish brown to puce. Picotite may occur in groups of grains or films. Its colour is olive green to umber-brown, and is dark between crossed nicols. The serpentine, which appears to result from the decomposition of the olivine, shows between crossed nicols a pale golden tint.[1]

The Lherzolite at Konradsreuth in the Fichtelgebirge, according to Gumbel,[2] is accompanied by an altered olivine slate now converted into talc slate and actinolite schist. It is associated with eklogite and diorite, and with them is contained in syenitic gneiss. The Lherzolite here, too, is converted into serpentine, and it is probable that many serpentines will prove to have been originally a rock of this kind, especially the serpentines of the Vosges, the Lizard, and the department of Var.

Dunite, originally described from New Zealand, consists of olivine and chromic iron. In the south of Spain, at Serrania de Ronda, the

[1] Bonney "On the Lherzolite of the Arriège," Geol. Mag., Feb. 1877.
[2] Gumbel, Fichtelgebirge, 1879.

Dunite is decomposed into serpentine. A similar rock appears at Kranbat in Upper Styria, and at several places in the Vosges, near St. Etienne, &c. There is rarely any enstatite or diallage, but both are found, and are sometimes decomposed into chlorite or amphibole.

Serpentine.

Serpentine is now known to result from reconstruction of the mineral constituents of many kinds of igneous rocks, especially of those rich in olivine and enstatite. The whole group of peridotites or olivine rocks may be converted into serpentines, though a few serpentines have been described to which no such origin can be attributed. Examples of olivine-serpentines have been enumerated under the peridotites; but at Todtmoos in the South Schwarzwald, a serpentine is seen which indicates that the rock from which it was formed consisted of a mixture of diallage and enstatite, and contained as accessories biotite and hornblende. In the Bluttenthal in the Vosges, the serpentines are said to be decomposed hornblende slates. But even in these cases it is difficult to affirm positively that the rock was always free from olivine; though nothing is needed for the production of serpentine but an abundant infiltration of silicate of magnesia in chemical combination with water. The ground mass is colloidal, and contains crystals and fibres of the minerals which it replaces. It is typically green. When serpentine occurs as an accessory, it may replace olivine, hypersthene, augite, or amphibole; but black mica, amphibole, and augite are more frequently converted into chlorite. MM. Fouqué and Lévy regard the viridite of volcanic rocks as a phase of serpentine. Any rock which includes these minerals may be more or less converted into serpentine. When serpentine results from the decomposition of enstatite, bastite is frequently formed.[1] Serpentine often occurs in schists, when it may be due to the presence of glauconite in the original sedimentary rock which was metamorphosed; in other cases it is certainly intrusive, but even then it may have had a similar metamorphic origin.

Serpentine in Relation to Diallage Rock.—The abundance of serpentine in the Pyrenees, Apennines, and other parts of the south of Europe, has long been known. Diallage rocks, which are equally abundant, often occur in connection with the serpentine, and there is now no doubt as to the fact that these two rocks are very intimately related. Few conclusions of this nature appear better authenticated by observation than the gradation of diallage rock into serpentine, in the Alps, the Apennines, Corsica, and Cornwall.

In the Northern Apennines Brongniart remarked the following general order of succession downwards:—1. Serpentine. 2. Diallage rock, in the upper part assuming the aspect of serpentine (at Rochetta, north of Borghetto, near Spezia), consisting partly of red crystallised limestone. 3. Jasper rock in thin laminæ. Below these are limestones and marly schists, common in the Apennines. In Monte

[1] Fouqué and Lévy, Roches Eruptives Françaises, 1879.

Ramezzo, north-west of Genoa, the serpentine rests on limestone and talc schist, the limestone is in thin tortuous beds, and is as it were dissolved with the shining slate and steatite-schist. The direction of the serpentinous masses in the Northern Apennines, to which the elevation of that part of the range is ascribed, is east-south-east, which is the same as that of the Pyrenees, and of some serpentine rocks about Como.

Serpentines of the Riviera.—West of Genoa several examples of dull-green serpentine are seen on the shore on both sides of Pegli. Several neighbouring headlands consist of gabbro, and both rocks, according to Professor Bonney, closely resemble those of Cornwall. Fragments of serpentine are brought down to the shore above Pegli by the Varenna Torrent, some full of crystals of bronzite, like the serpentine of Cadgwith in Cornwall. Serpentine forms the coast from Framura for several miles as far as Bonasola. It shows a sub-spheroidal structure, and is sometimes a rusty red, sometimes greenish. At Levanto, where the rock is quarried, one variety is purplish or brownish-black, veined here and there with dull green, and with crystals of bronzite. In other places it is lighter and greener. A gabbro, consisting of sassurite and diallage, here as elsewhere, is associated with the serpentine, and has an intrusive aspect.

Serpentines of Tuscany.—The celebrated Verde di Prato occurs at the village of Figline, about three miles from Prato, in the Lower Arno. This serpentine is of a purplish or greenish brown, and forms a large mass on the upper part of the hill. Through the ground mass are scattered small green crystals of enstatite and films of white steatite. The serpentine is intrusive, according to Professor Bonney, and he states that gabbro penetrates into the serpentine. As in so many other localities, microscopic evidence leads to the conclusion that these serpentines are altered olivine rock.[1]

Serpentines South-east of Leghorn.—Mr. Hamilton described the serpentine in the western part of Tuscany, S.E. of Leghorn. It extends from the copper mines of La Cava, and along the hills running from Monte Catini to Castellina. At Monte Rufoli it covers an area of many miles. At Monte Catini it is soft and soapy, of a grey-green colour. The copper ore lies between the serpentine and the red gabbro. The serpentine masses strike from N.W. to S.E., which is parallel to the axis of the Apennines. Veins of steatite, known as Pietra di Sarto, frequently occur in the serpentine, so as to have a commercial value. At Monte Rufoli the serpentine is covered with forests of ilex. Here occur the famous chalcedony quarries, which resemble quartz veins, but only extend a few feet below the surface. The serpentine around them is soft and decomposed. Serpentine is well exposed at Sibbiano, and at the village of L'Impruneta, where it often contains red veins. It is everywhere associated with the red gabbro.

[1] Bonney, Geol. Mag., Aug. 1879, p. 362.

CHAPTER XVIII.

THE HISTORY OF VOLCANIC ACTIVITY IN BRITAIN.

The British region was greatly disturbed by volcanic phenomena during the whole of the Primary period, and during the earlier portion of the Tertiary period volcanoes were active in Western Scotland; but except at its commencement in the Triassic rocks of the south-west of England, the whole of the Secondary epoch was free from volcanic outbursts. During a large part of the time recorded by the Primary strata, the British region was a volcanic archipelago throwing out vast quantities of volcanic ashes and lavas, which not infrequently form much of the thickness of some of the older Primary rocks.

Evidence for the Former Existence of Volcanoes.—The existence of these volcanoes is affirmed chiefly on the evidence of the volcanic ashes and agglomerates; for although intrusive lavas may be injected in sheets into strata and between them, long subsequent to their deposition, no source for volcanic ashes is conceivable except the throat of an active volcano. The very sites where such ancient centres of volcanic activity stood are usually unknown, and often only inferred, with more or less uncertainty, from dykes and bosses of volcanic rock. But although long since levelled, like Graham Island, and having the throats or necks covered up by later deposits, denudation, which has exposed the old strata forming the structure of the country, yields a history of volcanic action, which we propose to trace.

In the following pages we begin with the most ancient eruptions, and follow the outbursts of volcanic action during successive periods of geological time. If there be any general differences between modern and ancient volcanic effects, it is in part attributable to the circumstance that the modern phenomena best known to us are such as happen on land—*subaerial* eruptions—while the evidence of the ancient volcanoes is chiefly gathered from subaqueous lava streams, and submarine beds of ashes. Much of the modern andesite, trachyte, basalt, and other melted rock has been exposed by *eruption*, and indurated at the surface; much of the ancient porphyrite, felsite, and greenstone was solidified under the pressure of seas, and decomposed and indurated by prolonged infiltration.

Pre-Cambrian Volcanoes.

Pre-Cambrian Volcano of St. David's.—The oldest group of rocks in this country, named pre-Cambrian, is largely volcanic. The oldest portion, constituting the Dimetian formation of Dr. Hicks, is a variable rock, regarded as intrusive syenite by Professor Ramsay, and as intrusive granite by Dr. Archibald Geikie, in its typical exhibition at St. David's; and this part of the series is generally admitted to be everywhere free from volcanic rocks; but, so soon as we pass above these ancient gneisses, with their interstratified schists and limestones and granitoid rocks, and come to the series named by Dr. Hicks *Arvonian* and *Pebidian*, we find proofs of remarkable volcanic activity. It is possible that the so-called "Arvonian" formation is only the lower part of the "Pebidian." It consists chiefly of felsites of the type known as "hälleflintas," with quartz felsites and breccias. On the hypothesis of the so-called Dimetian being intrusive, this felsitic condition of the rock immediately above it is a matter of some interest, because it corresponds to the state in which the underlying rock would appear in its outer portion in consequence of rapid cooling, and a similar rock is found on the margins of many important masses of granite. According to the views of Dr. Hicks, these felsitic rocks are ancient rhyolitic lavas. The overlying Pebidian series, however, consist to a large extent of volcanic ash, interstratified with micaceous and chloritic schists. The lowest beds include, in the agglomerates, spherulitic felstone lava; and higher up are many alternations of felstone and volcanic tuff. Hence the whole series is precisely such as might have been furnished if the granitoid rocks of St. David's had been the base of an old volcano, and the materials ejected from it had sometimes decomposed into muds and sometimes formed ordinary volcanic rocks.

In North Wales the three subdivisions of pre-Cambrian rocks have been established by Dr. Hicks, Professor Hughes, and other observers, and show similar characteristics.

Pre-Cambrian Volcano of the Wrekin.—Mr. Allport, who has contributed greatly to establish the identity of volcanic rocks of the Primary and Tertiary periods, notices a narrow ridge of igneous rock which extends two miles and three-quarters through Ercal Hill and the Wrekin. A second ridge lies to the west. Both these rocks are highly acidic, and are associated with beds of volcanic ash greatly indurated, which are well seen on the south of Lawrence Hill.

The lavas are reddish-brown felsite, or altered pitchstone. They frequently exhibit on their weathered faces numerous parallel lines, which sometimes show complicated folding. These lines indicate the presence of streams of microliths, such as are seen in Hungarian perlites of Tertiary age. Sometimes the spherulitic rock of the Wrekin consists of bright-red spherulites, set in a grey or yellowish-

green matrix ; and under the microscope each central red spot and its border exhibit a radiated fibrous structure. Frequently the spherulitic structure is replaced by perlite structure, and when the rock is examined by the lens, it then shows small concave or convex surfaces. The original glassy base of these rocks has undergone the change of devitrification. Quartz veins are not uncommon in the rock, and nodules of chalcedony are abundant. The old lava contains 72 per cent. of silica, 14½ per cent. of alumina, 6 per cent. of potash, and 2 per cent. of soda.[1]

The volcanic agglomerates consist of ash of varying size, frequently somewhat vesicular, having the cavities filled with chlorite and crystalline quartz. Epidote is frequent in the coarser ash.

The Ercal is a hill overlooking Wellington, quarried for a bright red felspathic rock of a granitoid character, which suddenly changes to compact felstone, which is apparently the Wrekin rhyolite intrusive in the red rock. The north-east end of Lawrence Hill consists of felstones similar to those of Ercal, with felspathic tuff, which contains fragments of pitchstone and felstone.

The tuff which forms the Wrekin is continued and appears on the northern slope of Primrose Hill, and there intrusive diorite is found, which is similar to the diorite of the Malvern district.

The Lea rock to the N.W. is a great mass of rhyolite, remarkable for its spherulitic and perlitic structure.

In the pre-Cambrian rocks of Lillieshall Hill there are two ash bands, each about 10 feet thick, soft and ferruginous, and excavated by weathering. According to Dr. Calloway, the minimum thickness of the alternations of hornstone, ashy slates, shales, and felspathic agglomerates there seen is 1500 feet.

Other examples of the same alternations of pre-Cambrian felstones and tuffs occur at Rockwarden, where the felstones are spherulitic, at Charlton Hill, at both ends of Lawley Hill, the centre of which is an intrusive mass of greenstone. At Caer Caradoc there are also pre-Cambrian rocks with felstones and ashy shales, and the volcanic series is traced onward by Cardington Hill and Ragleth Hill. Hence the chain of hills which forms the axis of South Shropshire is of pre-Cambrian age, and largely formed of volcanic materials of a rhyolitic type, though sometimes broken through by dolerite and gabbro.[2]

Pre-Cambrian Volcano of Caernarvonshire.—In north-west Caernarvonshire, quartz-felsite or rhyolite is well exhibited in the vicinity of Bangor, Caernarvon, and Llyn Padarn. These rocks were regarded by Professor Ramsay as metamorphic, and as stretching for thirteen miles in the Cambrian strata. Professor Bonney[3] believes that the

[1] Allport: "Ancient Devitrified Pitchstones and Perlite," Q. J. G. S., vol. xxxiii. p. 449.

[2] Calloway: "Pre-Cambrian Rocks of Shropshire," Q. J. G. S., vol. xxxv. p. 643.

[3] Bonney: "Quartz Felsite in North-West Caenarvonshire," Q. J. G. S., May 1879.

rocks at Bangor, and part of those at Llyn Padarn, are ancient lava-flows, which in strictness should be termed rhyolites. This felsite, under the microscope, shows a ground mass containing crystalline grains of quartz, with orthoclase and plagioclase. The rock constantly exhibits the streaky structure characteristic of acidic lavas, while to the north-east of Llyn Padarn the felsite is associated with agglomerate. These masses are referred by Professor Bonney to the Pebidian group of Dr. Hicks.

On the eastern side of the Malvern Hills, near the Herefordshire Beacon, there is a small area of compact felsitic rocks of uncertain age, which Professor Bonney regards as probably Pebidian.[1]

Pre-Cambrian Volcano of Charnwood Forest.—In Charnwood Forest Professor Bonney and the Rev. E. Hill have described rocks probably of pre-Cambrian age, which consist of slates alternating with thick masses of rhyolitic agglomerate, less glassy than those of the Wrekin, and alternating with beds which appear to be composed of volcanic materials, sorted by water and somewhat triturated.

Cambrian Volcanoes.

Cambrian Volcanoes of North Wales.—The great importance of volcanic rocks in the history of the Cambrian Formations of North Wales may be best appreciated by examining a geological map, which represents on a sufficient scale the country from the south of Barmouth through Cader Idris, the Arans, and the Areing Mountains into Caernarvonshire. On the Geological Survey map broad strips of reddish colours indicate the areas now occupied by beds of volcanic ashes, felspathic lavas, and quartz porphyries, which were poured out from sub-aerial and sub-marine volcanoes during the whole of the Cambrian ages; and in the Malvern district the Hollybush sandstone contains dolerites which are interbedded, and at least as old as the Lingula Flags of North Wales. The lava occurs as lenticular masses, which now stand up in rounded bosses, because they have decomposed less rapidly than the muddy sediments in which they were covered up.

Volcanic Rocks in the Lingula Flags.—The Lingula Flags of North Wales in their higher beds so resemble volcanic ashes that between Capel Arthog and Penmaen, west of Dolgelly, there appears to be no doubt about their having originated in volcanic action. But, otherwise, the igneous rocks of the Lingula beds are for the most part dykes and intrusive masses of dolerite, though some masses of felsite occur. Many of these dykes run in the line of strike, but they are never interstratified, and there is no evidence of their geological age.

Volcanoes of the Tremadoc Slates.—Volcanoes were probably active during the succeeding Tremadoc period, for near the top of that series the slates contain pisolitic iron ore, such as, in other

[1] Holl: Q. J. G. S., vol. xxi. p. 72.

localities, is associated with volcanic rocks, and is known to result from their decomposition.

Arenig Volcanoes.—It was during the succeeding Arenig period that the volcanoes in the Welsh district attained their greatest activity. There are no remaining traces of the throats up which the igneous matter was ejected, for these outbursts seem analogous to recent submarine eruptions among the Canaries, which rose from the floor of a moderately deep sea, and in a few years were so completely worn away that no definite indications of their position can now be ascertained.

In Cader Idris the Arenig rocks include a jointed porphyry, somewhat hornblendic, and therefore possibly andesitic, which is 1700 feet thick, and extends northward continuously to beyond Aran Mowddwy. Upon these lava streams are 300 feet of blue slates, formed of muds which may have been to a large extent derived from the decomposition of volcanic materials; and higher up are 100 feet of porphyritic felspathic ashes, and finally 500 feet of a greenstone, which is full of air cavities, and therefore was poured out under moderate pressure of water or air. Many intrusive sheets of greenstone also occur. Lower down the mountain, the newer beds also alternate with felspathic ashes and lavas, which are rudely columnar, and are about 1500 feet thick; but Sir Andrew Ramsay is doubtful whether the lavas are really contemporaneous, and out of the 3600 feet of igneous materials interstratified with the slates, believes that only 400 feet of ash-beds can with certainty be regarded as derived from craters which were active during the Arenig period.

The Arans, however, have the same general structure as Cader Idris, and there is here less room for doubt as to the contemporaneous character of the interstratified igneous rocks, because the lavas have baked the slates over which they flowed, giving them the texture of porcelain, while the slates which rest upon the lavas are unaltered. The volcanic ashes are frequently vesicular, and sometimes water worn, and thin away rapidly on the north side of the Aran chain, as though that were furthest away from the volcanic crater.

Evidence of this thinning out of the ashes and lava is best exhibited in a table, constructed from Sir Andrew Ramsay's data:—

	Cader Idris.	Aran Mowddwy.	Moelddu.	Arenig.	Moelwyn.
	Feet.				
Upper ashes and agglomerates	100	traces	...	800	...
Felspathic lavas . . .	2850	2400	1150	250	400
Lower ashes and agglomerates	2700	3400	1100	...	2700

from which we learn that though the contemporary ashes and lavas extend from Cader Idris to the east of Festiniog, and though the ash

extends from six miles south of Barmouth to six miles west of Bala Lake, all the beds die away and disappear at a little beyond Tremadoc on the north, and towards Llanegryn on the south. The lower ashes have their greatest thickness in Aran Mowddwy, where the lava also is thickest. The lower ash disappears in the Arenig. The lavas have thinned to an insignificant amount in Arenig, while the upper ash there attains its greatest thickness. This deposit formed a lenticular mass 23 miles long, thinning away on the south near Penmaen, and on the north at Cwmorthim. The volcanic centres of this region are placed by Ramsay to the eastward of a line drawn from Tremadoc to Llangryn, and he suspects that the felspathic masses of Tyddyn-Rhiw and Gelli-llwyd-fawr near Dolgelly, and of Y-Foel-ddu near Aran Mowddwy, and part of the Arenig, are probably remains of the necks of volcanoes, because the lower ashes and felstones attain their greatest development near Dolgelly and Aran Mowddwy, and the upper ashes attain their greatest thickness near Arenig.

The greenstones do not appear to have at any time reached the surface of the country, and therefore it is difficult, if not impossible, to fix their age; even the great mass of Rhobell Fawr, which is seven miles long and three miles broad, appears to have been an intrusive overflow between planes of bedding, like the masses termed laccolites.

In the lake country contemporary volcanoes poured out great thicknesses of felspathic lava and ashes, which are interstratified in the formation known as Skiddaw slate.

Llandeilo Volcanoes.—In the succeeding period, known as the Llandeilo Flags or Lower Bala Rocks, volcanic action still continued with great vigour. In the group of greenslates and porphyries of the Lake district, the volcanic rocks make as prominent a feature as in strata of the same age in Wales; but according to Professor Bonney these are rather to be referred to the andesites, since they correspond to them in chemical composition.

The Volcanic Rocks of the Borrowdale Series.—The greenslates and porphyries of Sedgwick, termed the Borrowdale series by Professor Nicholson, cover a large area of the central part of the Lake district, extending 25 miles E.N.E. along the strike, and 13 miles S.S.E. in the direction of the dip. These rocks are estimated at 5000 to 6000 feet thick, and a large part of the thickness consists of ash beds and lava streams. In Borrowdale, the Skiddaw slates are overlain by dark-green compact lava, which is sometimes rudely columnar. This is succeeded by felspathic ash and agglomerate, with many minor beds of lava, the highest bands being amygdaloidal ashes, in which the cavities are commonly filled with quartz. These rocks are well seen rising through Cat Bells, Barrowside, Maiden Moor, and Narrow Moor. A similar sequence is seen in the valley of Gates Garth Beck, which flows into the head of Buttermere. In many places the ashes and breccias are cleaved, and form fine-grained slates, sometimes green, sometimes purple, as may be seen in the quarries at Dale Head and Honister Crag. Sometimes a subordinate bed of fine purple felstone occurs with large greenish crystals of felspar. Similar

beds are traced in the vale of St. John, in Matterdale, in Eycott Hill between Ulleswater and Haweswater, above Shap, and in other places.[1]

Volcanic Rocks of Bala Age.—The nodular felsites in the Bala rocks of North Wales are well exhibited in the valley of the Conway and Bettws-y-Coed, and have been studied by Professor Bonney near the Conway Falls Inn. On both sides of the house the rock is a compact felsite. It is succeeded by a bed with wavy laminæ and films of a green mineral, soon passing into more or less fissile and coarsely spheroidal rock, with nodules as large as a pigeon's egg, which, when weathered, give the rock the aspect of a conglomerate. Other sections are seen by the wicket-gate leading to Conway Falls from the road to Pandy Mill. The typical felsite is a compact bluish-grey rock, which shows corrugated structure under the microscope, due to the arrangement of microliths; and nearly all the specimens exhibit fluxion structure. The rock, which has a schistose character, contains vesicles, which have become infiltrated with crystalline quartz, and with limonite, so that the rock is identified as a vesicular rhyolitic lava. The nodular spherulitic rock shows no trace of a radial structure, but closely resembles the ordinary felsites of the neighbourhood. In the upper part of Conway Mountain, the yellowish felsite contains spheroids, sometimes two inches in diameter, and frequently hollow in the centre. This felsite is also seen in the Diganwy Hills, where the ovoid masses have a cherty aspect, but under the microscope they show fluxion structure like the matrix of the rock. The ordinary cream-coloured felsite of the Conway mountain has almost the aspect of a bedded mudstone. Professor Bonney accounts for the formation of the nodules by contraction of the vesicular rock, determined by the presence of a cavity, with roughly concentric cracking of the mass in cooling.[2]

Felstone of the Glyders. — In a lava-flow from the Bala beds forming the Glyders, on the north side of the Pass of Llanberis, Mr. Frank Rutley has described perlitic and spherulitic structure. The rock now termed felstone was originally a vitreous lava of the kind named rhyolite, and the felstone character is entirely due to devitrification.[3]

On the south side of the Capel Curig road, near Bedd-Gelert, is a greenish-grey rock, which shows the usual characters of a devitrified rhyolitic lava, with spherules one-eighth of an inch in diameter, arranged in bands. The spherules are an aggregate of minute colourless granules, probably garnets, and pale-green scales, probably of chlorite. The rock was originally a pitchstone or obsidian.

Another rock of a greenish-grey colour, which presents a banded

[1] Nicholson: "Greenslates and Porphyries of the Lake District," Q. J. G. S., vol. xxvii. p. 599.

[2] Bonney: "Felsites in the Bala Group of North Wales," Q. J. G. S., vol. xxxviii. p. 289.

[3] Rutley: "On Perlitic and Spherulitic Structures in the Lavas of the Glyder Fawr," Q. J. G. S., vol. xxxv. p. 508.

surface on weathering, is found in the Bala beds, about a mile N.W. of the summit of Snowdon, and closely corresponds with obsidians from volcanic districts in its fluxion structure.

A dark-grey felstone, with a fissile structure, is seen between Pont-y-Gromlech and Gorphwysfa, so that it might be termed a felsite schist, or an indurated volcanic ash, unless examined under the microscope; but its microscopic texture corresponds with many obsidians and rhyolites, and is probably to be regarded as a devitrified obsidian, because the base is entirely devoid of crystalline structure.

Skomer Island, off the coast of Pembrokeshire, contains volcanic rocks which are associated with strata belonging to the Llandeilo or to the Bala series. They are banded and spherulitic, and what were once obsidians are now felstones. They closely resemble those of the Yellowstone district of the United States. With the felstones occur other rocks, classed by Mr. Rutley as basalt, and as quartz oligoclase trachyte.[1]

The Silurian period, comprising the Wenlock and Ludlow rocks, appears to have been one in which volcanic action was intermitted.

Devonian and Old Red Sandstone Volcanoes.

Old Red Sandstone and Devonian Volcanoes.—With the Old Red Sandstone and Devonian period, eruptions began again with great vigour, but their locality is removed from Wales and the Lake district. Interbedded volcanic rocks abound in North Devon, West Somerset, and South Devon; but northward there is no trace of an Old Red Sandstone volcano till we reach the south and centre of Scotland.

Volcanic Peaks of the Grampians.—Professor Judd has drawn attention to a series of granite masses which burst through the Cambrian strata; and, forming the axis of the Grampian chain, extend from the Ross of Mull in the S.W. in a N.E. direction to Peterhead. The largest of these masses are Cairngorm, Ben Nevis, and Ben Cruachan. Professor Judd remarks, that when the granite boss is greatly denuded, as in the Ross of Mull, the rock exposed is a typical granite; but where it rises into lofty peaks, it becomes more and more hornblendic, and graduates externally into a felsite, which is more or less porphyritic. Everywhere, when in contact with stratified rocks, the granite sends veins into them, which demonstrates that it was sufficiently heated to be rendered fluid by the removal of the rock pressure upon it; and the existence of the fissures now filled with granite is an evidence of the influence which such alteration of pressure exercised. Professor Judd's section of Ben Nevis may be regarded as demonstrating that lava and ashes were poured out from old volcanoes, of which the granite bosses of the Grampians are the cores. The Ben Nevis rocks consist at the

[1] Rutley: "Devitrified Rocks from Bedd-Gelert and Snowdon," Q. J. G. S., xxxvii. p. 403.

top of felstone lavas, alternating with volcanic agglomerates; below these is a bed of felsite resting on another felsite, which graduates downward into a fine-grained granite. Under this is the coarse porphyritic granite, which burst through the Cambrian rocks. On the one hand, it graduates into syenitic granite, and on the other into granite, consisting of orthoclase, oligoclase, quartz, and hornblende.

Thus the granite graduates externally into such rocks as granite is known to become when it cools rapidly, and it is overlain by such lava and ashes as would have been poured out from a volcano having a granitic base. Therefore, when it is found that great lava-sheets in the Scottish Lowlands are associated with the Lower, Middle, and Upper Old Red Sandstone in the district of Lorne, that lava streams also occur upon the northern flank of the Grampians, and that the hill ranges of southern Scotland are composed of volcanic rocks, it seems highly probable that the Grampian range was elevated as a chain of volcanic islands,[1] not unlike some of those which now occur in the Indian Ocean or the Pacific.

The activity of these volcanic centres during the Old Red Sandstone and succeeding Carboniferous periods, must have been largely determined by the action of the compressing forces which elevated those areas out of the ocean; and it is worth remarking that the Old Red Sandstone is a shallow-water deposit, even if it was not of lacustrine origin.

Cheviot Andesite Lavas.—The Cheviot district consists chiefly of quartzless porphyritic rock, such as is usually termed porphyrite. Under the microscope it is a compact felsitic ground mass, usually purple or red, with crystals of triclinic felspar. Volcanic ash and breccia are found on both the English and Scotch sides of the eruption. And a black resinous rock, which has been called pitchstone-porphyrite, occurs near Cherrytrees in Roxburghshire, in a cliff near Yetholm, in the Coquet between Windy Haugh and Blindburn, and in the Usway between Battleshields Haugh and Fairhaugh. These rocks belong to the same group as ordinary porphyrites, and are regarded by Mr. Teall [2] as ancient altered andesites, belonging to the Lower Old Red Sandstone period, during which the Pentland, Ochil, and Sidlaw Hills were formed. Porphyrites of later date occur about Kelso, which belong to the Tuedian beds at the base of the Carboniferous formation. These rocks can scarcely be distinguished from the andesites of Santorin, and Tokaj in Hungary. The felspars in the ground mass form a felted aggregate of microliths. The augite in most if not in all the andesites is subordinate to a rhombic pyroxene which is regarded as hypersthene. An andesite lava from near the summit of Ararat, contains a twinned monoclinic and a dichroic pyroxene; and this condition is found in the andesites of Southern Servia, and the districts near Schemnitz, Kremnitz, and Eperies. The Cheviot andesite gives on analysis—

[1] Judd, Q. J. G. S., vol. xxx. pp. 295, 289, &c.
[2] J. J. H. Teall: Geol. Mag. March, April, May, 1883.

Silica	63·0	Magnesia	2·8
Alumina	14·9	Soda	4·0
Iron Oxide	4·7	Potash	1·9
Lime	4·8	Loss	4·0

Thickness of Volcanic Rocks of the Lower Old Red Sandstone.—In the Lower Old Red Sandstone country, between the base of the highland mountains and the southern uplands, there were two lines of contemporary volcanic vents from which vast lava streams and accumulations of ashes were emitted.

Notwithstanding denudation, more than 5000 feet of volcanic rocks are measured at the northern end of the Pentland Hills, without reaching the top; and in the Ochill Hills more than 6000 feet of similar rocks are seen without reaching the bottom. The Sidlaw and Ochill Hills are composed of felstones and porphyrites, interbedded tuffs and agglomerate, which extend for 60 or 70 miles, and rise 2000 feet above the sea.[1]

Volcanoes of the Middle Old Red Sandstone.—The Middle Old Red Sandstone of Ayrshire abounds in interbedded rocks of volcanic origin. They are often very slaggy and amygdaloidal, and are seen in successive layers on the coast at Turnberry Point. The porphyrites are generally separated from each other by thin beds of sandstone. The Kirkoswald, Maybole, and Brown Carrick districts show the volcanic rocks of the Middle Old Red Sandstone, forming conspicuous hills of pink porphyrites and dark compact dolerites; and towards the N.W. they sometimes pass into a kind of coarse sandy tuff. Volcanic rocks form the range of cliffs at Culzean, where the porphyrites are dark green or purple. The porphyrite series ends on the shore near the heads of Ayr. In the Straiton and Dalmellington district the Middle Old Red Sandstone reappears, with similar massive porphyrites to those of the Brown Carrick Hills.

In this district the Lower Old Red Sandstone also contains dark-purple, fine-grained, amygdaloidal porphyritic rocks.

Further east, the middle of the Lower Old Red Sandstone is almost entirely made up of purple and greenish slaggy and amygdaloidal tuffs, with occasional bombs of porphyrite.

The upper volcanic series is well seen in the district south of Irvine, overlying sandstones with *Cephalaspis Lyelli;* and similar rocks occur on the same horizon in Lanarkshire.[2]

Volcanoes of the Upper Old Red Sandstone.—In the Upper Old Red Sandstone of the Pentland Hills great consecutive sheets of felstone, with occasional bombs and volcanic ash, are interbedded. The larger beds, such as the felstone of Kips Hill, extend to the S.W. for six or eight miles. The lowest bed, forming Warklaw Hill, is a compact blue rock, which in its higher part becomes porphyritic and amygdaloidal, and ultimately vesicular. It is succeeded by pale rose-

[1] "Carboniferous Volcanic Rocks of the Firth of Forth," Trans. Roy. Soc. Edin., vol. xxix. p. 441, and Brit. Assoc., Dundee, 1867, sec. p. 49.

[2] Mem. Geol. Survey, Scotland; Explanation of Sheets 13, 14, 15, 22, 23.

coloured felstones, and various other felstones follow, interstratified with ash and agglomerate.[1]

The prevailing porphyrite extends into Peeblesshire, Lanark, and Ayr. It forms the greater part of the hills between the Lyne Water and the Clyde, but the true bedded character is less marked there than in the Pentland Hills. The porphyrites thicken to the S.W. towards Symington, where several necks of felstone probably mark volcanic vents.[2]

Devonian Volcanoes of Cornwall.—Prior to the upheaval of the great masses of granite of Devon and Cornwall, and during the deposition of the Devonian rocks which those upheavals disturbed, enormous quantities of doleritic lavas were poured out from volcanoes in the Cornish area. The recognition of the igneous rocks is not always easy, because the old slates are frequently so metamorphosed as to put on the characters of doleritic rocks; and trap rocks and ash beds so graduate into slates that the change is almost imperceptible Their history has been unravelled almost entirely by Mr. John Arthur Phillips, F.R.S. The largest group of these rocks is situate in the neighbourhood of Penzance, where they consist of a series of fissile greenish slates, containing compact crystalline beds without trace of lamination. Several beds are well seen around the shores of Mount's Bay.

Those slates which have undergone the least metamorphism consist of crystalline felspar or diallage, magnetite, titanic iron, and occasional specks of pyrites, prisms of apatite, and flakes of brown mica. The more altered rocks consist of a colourless transparent base, through which hornblende and viridite are diffused, with pseudomorphs of augite and decomposed felspar. On the eastern side of the Valley of Tollarn the large crystals of felspar are well preserved. The rock at Battery Point, and the Chapel Rock, are hornblendic lavas; but Mr. Phillips regards the hornblende as being, sometimes at least, a product of metamorphism. These rocks contain from 43 to 47 per cent. of silica, 18 to 21 per cent. of alumina, 9 to 11 per cent. of ferrous oxide, 6 to 12 per cent. of lime, 4 to 7 per cent. of magnesia, and 1 to 3 or 4 per cent. of potash and soda. The composition of the killas, or Devonian clay-slate, is often almost identical, and though the percentage of silica is sometimes higher, it may also be lower. Other altered dolerites occur in the Gurnard's Head; and the headlands at the extreme limit of Porthglaze Cove are so changed that apatite is the only unaltered mineral remaining. In the St. Ives Bay district the rocks are very similar to those in Mount's Bay, and it is just as difficult to distinguish whether the dark mineral in the rock was augite or diallage. There is usually present some granular quartz and a little viridite. Near Camborne an igneous band occurs, stretching further east to South Roskear, which is known as blue elvan, and consists of garnets and axinite. Two miles west of

[1] Geikie: Mem. Geol. Surv. Scot. Edin., 1861.

[2] Mem. Geol. Surv. Scot.; Explanation of Sheet 24. Arch. Geikie.

Camborne a bluish-green dolerite, with a slaty structure, stands out some 30 or 40 feet above the surface. It is hornblendic, and closely resembles the hornblendic slates of Penzance; and many other rocks which have been classed as greenstones are also hornblendic, like the beds at Newlyn East. At St. Stephens there is another blue elvan, which has many of its felspar crystals replaced by schorl and cassiterite, but like all the other rocks has the chemical composition of dolerite. Blue elvans are only met with in the neighbourhood of granite.[1]

A mile west of St. Austell there is a dolerite which extends in a south-easterly direction to the sea near Duporth. It is about 90 feet thick, and only preserves crystalline structure in the central part. Occasionally orthoclase is present with the plagioclase; the augite is frequently replaced by hornblendic pseudomorphs. In the cliff section at Duporth, the rock has the aspect of an aggregation of boulders cemented by a mineral like asbestos. This is due to decomposition along lines of fissure. Various other altered dolerites occur at Tregorrick and Hallane.

Another greenstone region stretches from Trevose Head on the west to beyond Camelford on the east. Near the coast the rocks consist of foliated ash beds, vesicular lavas, and augite lavas. When the rock is vesicular it is often termed dunstone. At Pentire Point there is a dark-green lava with abundant microliths of hornblende. The dolerite at St. Tidy is composed of plagioclase, viridite, green hornblende, with minute garnets, a little apatite, and occasional grains of quartz.

The ancient lavas of Northern Cornwall have often a greenish-grey colour and an amygdaloidal structure. At times amorphous, they are frequently divided up into blocks by joints, and at other times occur in foliated sheets, foliation evidently resulting from the movement of the rock in a fluid state. The amygdaloidal lava of Pentire Point contains 43 per cent. of silica. The cavities are generally filled with crystalline calcite and viridite, or quartz and chlorite. Near South Petherweir the dolerite is almost entirely unaltered. Near Liskeard, dolerites are well developed; and in South-East Cornwall vesicular lavas again become plentiful. The transformation of the augite into hornblende often begins with an external hornblendic fringe, and at last the crystal is replaced by a mass of hornblende microliths, but sometimes the augite becomes converted into uralite. Mr. Phillips suggests that some of the slaty hornblendic rocks which have the composition of dolerites may originally have been flows of volcanic mud; such rocks are limited to Western Cornwall. The interstratified condition of the vesicular lavas admits of no question, but the eruptive dolerites also are probably of the same age as the strata in which they occur, because they do not traverse the granite, but are disturbed by it.[2]

[1] J. A. Phillips: Q. J. G. S., vol. xxxii. p. 155.

[2] J. A. Phillips: "On the so-called Greenstones of Central and Eastern Cornwall," Q. J. G. S., vol. xxxiv. p. 471.

Volcano of Brent Tor.—Mr. Allport suggested that Brent Tor, which is four miles west of Tavistock, presents many of the features of a volcano. The rocks consist of purple-bedded ash, with vesicular and amygdaloidal dolerites, described by Mr. Rutley[1] as having a fissile texture, and abounding in small crystals. They sweep round Brent Tor in a semicircle, dipping from it at a low angle; and it is suggested that the old volcano has been faulted through the cone, so that the ashy beds, by being thrown down, are much better preserved on one side than on the other. The altered dolerite about Tavistock is probably only a prolongation of the lava-flows from Brent Tor.

On the east of Dartmoor there are several dolerites of similar character. Those seen near Hennock, to the N.E. of Bovey Tracy, have the augite but slightly altered. Near Torquay eruptive dolerites are exposed in Babbicombe Bay and in Austis Cove. These dolerites are converted into a serpentinous rock at Clicker Tor, S.E. of Liskeard, but more frequently show the alteration due to the development of hornblende.[2]

Volcanic Rocks of the Mendip Hills.—At Down Head Common, near Shepton Mallet, is a large exposure of intrusive rock, which was regarded by Mr. Charles Moore as a dyke. It occurs in the Old Red Sandstone. At Down Head the rock appears to be a felstone of dark-grey colour, with minute crystals of hornblende and much magnatite. At Stoke Lane in the Mendips, the lava has the characters of a pitchstone porphyry. It is a brownish-grey rock, with minute vitreous crystals, which are colourless or greenish. Under the microscope it is seen to consist of orthoclase and plagioclase, with a little magnatite and a green mineral termed viridite. Mr. Rutley has also described basalts and dolerites from the Uphill Cutting, Great Western Railway; Wrigton Warren, near Bristol; Wood Spring Hill, Charfield Green, and Damory. Some of these lavas are amygdaloidal, and some are greatly decomposed.[3]

Felsite of Bittadon.—This is an intrusive mass in the grey unfossiliferous slates which form the upper part of the middle Devonian rocks, and like the slates is affected by cleavage, so that Professor Bonney dates its intrusion before the close of the Carboniferous period. It was originally, he says, probably a sanidine trachyte, with hardly enough quartz to be a rhyolite, and may have been not unlike some of the Drachenfels trachyte; but the original minerals have undergone much alteration. The mass of the rock is greenish-grey, thickly studded with small reddish-white crystals, which are mostly orthoclase. A few small grains of quartz are visible. Under the microscope it is crowded with indistinct microliths, brown and green granules, and occasional black specks and

[1] F. Rutley: "On Schistose Volcanic Rocks on the West of Dartmoor," Q. J. G. S., vol. xxxvi. p. 285.

[2] Allport: "Metamorphic Rocks Surrounding the Land's End," Q. J. G. S., vol. xxxii. p. 418.

[3] Q. J. G. S., vol. xxiii. p. 452; and Mem. Geol. Survey: East Somerset and Bristol Coalfields, H. B. Woodward, pp. 14–208.

yellowish-green streaks. There is a little plagioclase, but the base appears to be chiefly formed of sanidine. Though clearly intrusive, the rock resembles some of the altered volcanic ash in the volcanic series of Borrowdale.[1]

Carboniferous Volcanoes.

Carboniferous Volcanoes of South Staffordshire.—In the South Staffordshire Coalfield there are several masses of basalt, some of which appear to be interstratified with the coal measures.[2] The most important of these outbursts is the columnar basalt, which spreads over an area two miles long by one mile broad in the Rowley Hills, near Dudley. There occur sometimes, just under the basalt, considerable beds of volcanic ash and agglomerate, which seem to show that the lava was ejected in a true volcanic eruption. The coal, on which it rests, is altered so as to become earthy, and has nearly lost its inflammability. Where this change has taken place, veins sometimes penetrate the coal, which consist of what Professor Jukes termed "white rock," chiefly distinguished from basalt by yielding on analysis a large percentage of carbonic acid and water and a small percentage of silica, differences which Professor Jukes attributed to the assimilation of a portion of the coal by the basalt vein. There is no trace of the original throat through which the basalt was ejected. Some of the basalts of the Dudley Coalfield appear to be on a different horizon from that of the Rowley Hills, which is 600 feet above the thick coal.

Among the minor masses is one at Barrow Hill, 10 miles west of Dudley. A smaller columnar mass occurs at Pouk Hill, near Walsall, and is below the thick coal. A fourth mass is seen south of Netherton. Professor Jukes also distinguishes, under the name of greenstone, sheet-like masses of basaltic rocks which occur in the lower coal-measures between the Rowley Hills up to Wolverhampton, Bilston, and Bentley. On the whole, these eruptions may be referred to the close of the Carboniferous period, because the rocks have been faulted with the coal-measures, so that the more important sheets appear to be contemporaneous.

Mineral Character of the Carboniferous Dolerites.—Dolerites in the South Staffordshire Coalfield are quite typical. In the Rowley Rag the texture is finer than at Pouk Hill. The plagioclase occurs in the usual long prisms, well striated, mixed with pale-brown augite, with green pseudomorphs of olivine, a mineral which at Pouk Hill is usually unaltered. There is always some apatite and a little amorphous glass.

At Deep More, N.W. of Walsall, the dolerite is usually much altered, so that the felspar is replaced by chlorite, and chlorite is distributed throughout the rock. Where it meets the coal or shales, it

[1] Geological Magazine, 1878, p. 207.
[2] Jukes' Mem. Geol. Surv. South Staffordshire Coalfield, 1859.

becomes nearly white, and then its constituents are completely decomposed, though the felspar is usually unaltered. The Titerston Clee Hills are capped by columnar dolerite, in which the olivine is nearly unaltered. A similar rock is found at Knowle Hill near Kinlet, but where in contact with the sandstone on which it rests, both the augite and felspar are converted into a yellow granular substance. At Whitwick colliery, where unaltered New Red Sandstone rests on dolerite, most of the augite has a purple tinge. The dolerite ridge near Shatterford has the minerals altered only above the sides of fissures, and in places assumes a porphyritic texture, when it abounds in grains of magnetite. At Swinnerton Park, eight miles N.E. of Stafford, the rock abounds in augite and olivine, with comparatively little plagioclase.

Diorites of Warwickshire.—In the Warwickshire Coalfield diorites occur in the district about two miles south of Nuneaton. The several bands and masses are limited to the lower part of the coal measures, which are here unproductive, and to the millstone grit. They run in the planes of bedding, but are clearly intrusive, since the rock is altered above and below them. They are well seen in the railway cutting near Chilvers Coton. The eruption was previous to the deposition of the Trias. These diorites vary a good deal in composition. That seen near Marston Jabet has the external appearance of basalt, and contains small crystals of hornblende of a clear-brown colour, lying in a matrix of triclinic felspar, with numerous grains of magnetite, and a few hexagonal needles of apatite. But sometimes the ground mass is a good deal altered, being converted into a substance like serpentine, and the felspar becomes turbid. The diorite of Purley Park, near Atherstone, consists of a mass of plagioclase crystals, with a few crystals of orthoclase. Crystals of brown hornblende are abundant, and crystals of yellowish augite frequent. There are many pseudomorphs after olivine, usually replaced by calcite and viridite. This is the only augite-diorite recorded in this country, but the quantity of augite varies much in different specimens.[1]

Basalt in Arran.—Much of the southern half of Arran consists of sheets and masses of basalt of Carboniferous age, with intrusive sheets in places. The dolerite of the Clauchland Hills extends eastward to Dunfion, and reaches the coast at Clauchland Point. A similar sheet caps Ross Hill, near Lamlash. Sheets of dolerite form a succession of terraces in the cliffs between Deppin and Benan Head on the S.E. coast, and these three or four sheets are traced inland in the beds of streamlets. The lowest sheet, seen at Kildonan Castle, has the characters of an augite-andesite. On Auchenhew and Levencorroch Hills the dolerite is columnar.[2]

Trees in Volcanic Ash in Arran.—On the north-east coast of Arran, near the base of the carboniferous series, eleven distinct beds of volcanic ash occur in a distance of 400 feet, alternating with layers of shale and coal, which are inclined at an angle of 37°. Mr. E. A. Wünsch records the occurrence of twelve or fourteen stumps of

[1] Allport: "Diorites of Warwickshire Coalfield," Q. J. G. S., vol. xxxv. p. 637.
[2] Allport: "Carboniferous Dolerites," Q. J. G. S., vol. xxx.

trees in the volcanic ashes on two or three distinct horizons. The height of the trunks is limited by the thickness of the ash, which is three feet.[1]

Quartz-Felsite of Corriegills.—Professor Bonney has drawn attention to the great quartz-felsite dyke in Arran, on the Corriegills shore, south of Brodick, as having the base traversed by parallel joints which divide the rock into plates like tiles. Higher up there is rude vertical prismatic jointing, and higher still a recurrence of the platy structure. Other examples of predominant fissile structure are seen in the pitchstone veins at Corriegills and Dunfion, while the latter rock at Tormore is sometimes also rudely columnar.

The great pitchstone at Corriegills shows under the microscope quantities of microlithic dust, with larger belonites, either singly or in groups, aggregated in patterns like algæ. Sometimes the pitchstone shows a rough perlitic structure.

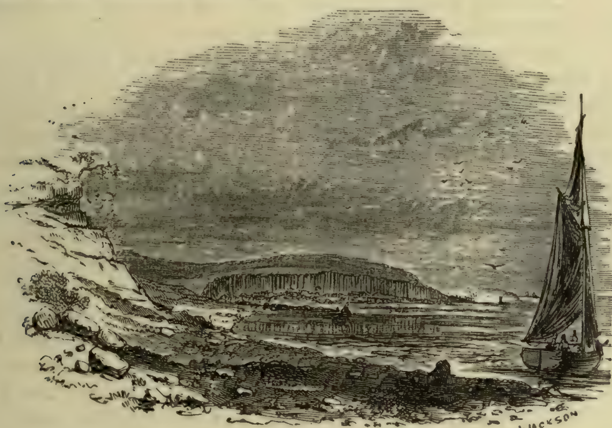


Fig. 59.—Drumadoon (Arran).

On the shore north of Drumadoon the felsite is divided by a dyke of basalt. On the one side of the dyke the felsite is compact and flaggy, but on the other side it is porphyritic.[2]

Arthur's Seat.—One of the most interesting remains of an extinct volcano of the latter part of the Primary period is seen in Arthur's Seat. There the strata consist of sandstones and shales of estuarine origin, which belong to the lower part of the calciferous sandstone, and alternate with stratified tuffs and sheets of dolerite and felspathic lava. These rocks dip N.E. about 20°, and form part of a great anticlinal fold. Through these carboniferous rocks rise masses of lava, dykes, and piles of volcanic agglomerates. Professor Geikie formerly referred this latter outburst to the Permian period, but Professor Judd has adopted the view that the interstratified lavas, and

[1] E. A. Wünsch: Trans. Geol. Soc., Glasgow, 1865–66, p. 97.

[2] Bonney: "Pitchstones and Felsites in Arran," Geol. Mag., 1877.

those which formed the core of the old volcano, are portions of one continued eruption; so that, according to the latter writer, the history of Arthur's Seat, after the formation of the fundamental rocks in the Lower Carboniferious period, included the eruption of ashes, basalts, and augite-andesites, and the injection of the great masses now known as St. Leonard's Crags, Salisbury Crags, and Samson's Ribs. Fossils are found in the stratified tuffs of St. Anthony's chapel, showing that the eruption was at first submarine. Coarse agglomerates lie around the central basaltic throat of Arthur's Seat, just as they would do around the eruptive throat of a volcano, though Professor Judd suggests that the position of the eruptive outlet may have been changed from time to time.[1]

Mineral Character of the Lavas near Edinburgh.—Arthur's Seat exhibits examples of contemporary interbedded dolerites in the masses known as Long Row, the Haggis Knowe, and St. Anthony's Chapel. The rock sometimes shows a fluidal structure, the long axes of the felspar prisms being more or less parallel to each other. The intrusive dolerites of Arthur's Seat form the three ridges known as Mount Heriot, Salisbury Crags, and the Dassies. In the Salisbury Crag bed, the felspar and augite crystals are sometimes visible to the eye, and are associated with grains of calcite and analcime, with prehnite and pectolite. It always contains crystals of orthoclase as well as plagioclase. Calcite appears to have replaced part of the glassy matrix. The Dassies consists of a rock which is partly decomposed, and is green from the chlorite developed in it.

At Dalmahoy, eight miles S.W. of Edinburgh, the black dolerite is semi-crystalline. At Ratho the rock is coarse-grained, with the augite sometimes altered into a fibrous, brownish-green substance. Similar rocks are seen at Springbeth, near Queensferry on the Forth. At Corstorphine Hill the rock is described by Mr. Allport as a true gabbro; it is a granular compound of plagioclase, diallage, and a little magnetite, with serpentine occupying the interspaces between the constituents.[2]

Salisbury Crag.—In Salisbury Crag is a very fine section of basalt in places 80 feet thick, enclosed between stratified sandstone, conglomerate, shale, and ironstone nodules, and it is easily seen that both the igneous and sedimentary rocks were altered at their formation. Masses of sandstone and conglomerate, of various forms and magnitudes, are insulated in a confused manner within the basalt, and portions of basalt interposed among the sandstones. No dyke appears; but small veins of calcareous spar, occasionally metalliferous, cross the line of junction. The accompanying drawings and references will sufficiently explain the most interesting phenomena observed, and give a general view of the face of the cliff as it appeared to Professor Phillips in 1826. The letters of reference, *a*, *b*, *c*, mark points of which details are given below. On a nearer examination, the point *a* shows basalt gradually changing to a red colour and finer

[1] Judd: Q. J. G. S., vol. xxxi. p. 131.
[2] Allport: Carboniferous Dolerites, Q. J. G. S., vol. xxx.

grain near its upper surface, on which rest beds of sandstone, ironstone, and shale, as under :—

1. The upper part of a dolerite mass, fine grained, and of reddish colour. Veins of calcareous spar, with micaceous iron ore, divide the upper part of this mass, and pass through Nos. 2 and 3 above.
2, 3. Mass of siliceous sandstone, mixed with softer green portions.
4. The same sort of hardened sandstone, with less of the softer parts (here and there a purple tinge).
5. Argillaceous, compact, hard shale of a purplish or green colour, and subconchoidal fracture.
6. Red argillaceous ironstone in green shale.
7. Sandstone beds, reddish and indurated.

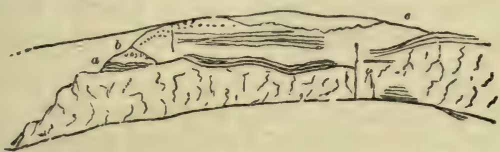


Fig. 60.

At the point *b* (fig. 60) a nearly similar series of alternating stone and shale rests on very similar dolerite. A portion of sandstone is engaged in the trap, and other signs of violent intrusion occur.

Fig. 61.

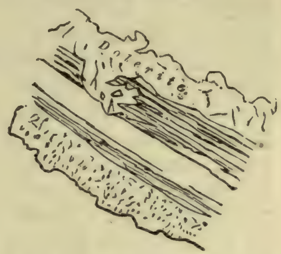


Fig. 62.

At the point *c* (fig. 60) hard red sandstone flags, without ironstone, rest on reddened greenstone.

A large quarry at the south end of Salisbury Crag affords an ex-

Fig. 63.

Fig. 64.

cellent section of sandstone beds *below* the dolerites. Figs. 61 and 62 are taken from this quarry.

In fig. 63 the dolerite, reddening below, rests on jasperised sandstone, which is much broken and confused in places. Below this is

green shale, covering red and white sandstone with conglomerate. Fig. 64 shows portions of sandstone enclosed in the dolerite, which grows redder towards the contact with the strata below. The aspect of a portion of sandstone fairly enclosed in dolerite is seen in fig. 64.

The Basin of the Forth.—Professor Archibald Geikie distinguishes six districts in the basin of the Firth of Forth which were characterised by volcanic activity during the Carboniferous period. These are—1, Edinburgh; 2, Haddingtonshire; 3, Linlithgowshire; 4, Stirlingshire; 5, West Fife; 6, East Fife.

Volcanoes of the Edinburgh District.—In the Edinburgh district the eruption began about the close of the Old Red Sandstone period, when volcanic activity was general over the southern half of Scotland. It formed the hills known as Arthur's Seat, Calton Hill, and Craiglockhart Hill. In this district the earlier lavas are dolerites, and the later lavas are termed by Professor Geikie porphyrites. Arthur's Seat is regarded as a prolongation of the old volcanic ridge of the Pentland Hills, and is hardly two miles from the great vent on the Braid Hills. The maximum thickness of the volcanic rocks at Edinburgh is about 500 feet.

Volcanoes of the Haddington District.—The East Lothian or Haddington district covers an area of about 65 square miles, and includes the Garlton Hills, and most of the coast from Dirleton to Dunbar. The volcanic masses here reach a thickness of about 1500 feet, and consist largely of tuffs, interstratified with various sedimentary deposits. The oldest lavas are dark-red augitic rocks; and the later lavas are dull red, pink, grey, brown, yellow, and white porphyrites. On the coast, both east and west of North Berwick, many old volcanic throats are seen, sometimes consisting of agglomerate, sometimes of basalt. North Berwick Law, the Bass Rock, the headland of St. Baldred's Cradle, and Traprain Law, are cited by Professor Geikie as examples of these necks; and he observes that volcanic action was prolonged in East Lothian after it had died out in the Edinburgh district.

Volcanoes of the Linlithgow District.—In the West Lothian or Linlithgow district there were many volcanic cones. The Binns Hill of Linlithgow is one of these, consisting of fine green tuff, 350 feet thick; and S.W. from Binns the volcanic cones are grouped close together, and threw out both ashes and dolerite. The thickness of the volcanic rocks of the south of Linlithgow is about 2000 feet. The intrusive sheets are of a later date, and Professor Geikie suggests that some of them may be overflows from Tertiary dykes.

Volcanoes of Stirling.—The Stirlingshire district embraces the Eastern prolongation of the Campsie Fells, which consists chiefly of porphyrites and tuffs at the base of the carboniferous system. These rocks are 1000 feet thick at Kilsyth, and thin away to the east, so as to disappear about a mile north of Stirling, which is 13 miles from Kilsyth. Subsequently thick sheets of dolerite extended from Kilsyth round the base of Campsie Fells to beyond Stirling. They

are intruded into the carboniferous limestone, but are probably of carboniferous age.

Volcanoes of Fife.—The volcanic rocks of Fife are separated by the Dysart and Leven Coalfields. In West Fife one group of old volcanic vents was situate in the district now occupied by the Saline and Cleish Hills, and is represented by some cones of fine green tuff. Another group lies six or eight miles to the east, near Burntisland. The tuffs and lavas occupy nearly the whole interval between the Burdie House limestone, and the base of the carboniferous limestone. The interstratification of the rocks is well seen on the coast between Burntisland and Kinghorn, especially between Pettycur and Seafield Tower. These volcanic outbursts are contemporary with those of West Lothian, and the basalts reach a thickness of upwards of 1500 feet.

The East Fife district contains an extraordinary number of volcanic vents, several of which are well seen on the coast. They extend in a band six miles wide from Leven to St. Andrews, where about fifty volcanic vents are now filled with tuff and agglomerate or masses of basalt; but these rocks are almost unconnected with interbedded volcanic rocks. The outbursts probably belong to the close of the Carboniferous period.

Professor Geikie remarks that the Campsie Fells and Kilpatrick Hills are only the north-eastern extremity of the great volcanic plateau of Dumbartonshire, Renfrewshire, and Ayrshire, and that the Garlton Hills of Haddington are to be connected with the outbursts along the southern flank of the Silurian uplands from Duns in Berwickshire; by Kelso, Ruberslaw, Langholm, Birinswark, and the Annan, to the mouth of the Nith at the foot of Criffel.

The Clyde Basin.—In the Clyde Basin Coalfield interbedded dolerite and ash form the hills of Kilsyth, Campsie, and Kilpatrick on the north, and the Renfrewshire hills on the south, where they occur at the base of the carboniferous limestone. The intrusive sheet of the Necropolis Hill, Glasgow, is a micaceous dolerite, sometimes dark grey, sometimes reddish brown.[1]

Varieties of Doleritic Rocks in Scotland.—Dr. Archibald Geikie describes the augite-felspar rocks in three varieties, which he terms diabase, dolerite, and basalt. The diabase is more coarsely crystalline, varies in colour with the tint of the felspar and with the development of decomposition, so that although some are pink, most are green. They are never amygdaloidal. Orthoclase usually occurs to the almost total exclusion of plagioclase, and when plagioclase does occur it is probably never labradorite. Augite is the most conspicuous mineral under the microscope, and is but little altered. The other minerals are titaniferous iron and apatite. No olivine crystals are seen, though serpentine occurs as a decomposition product. Quartz is occasionally present, but usually as a product of decomposition. Brown biotite and small prisms of hornblende are found when the rock is greatly altered.

[1] Allport: "Carbon Dolerites," Q. J. G. S., vol. xxx.

These dolerites in Scotland present no differences from those of Tertiary age. The rock has usually a dark-grey speckled character, and seldom contains orthoclase or any original quartz. Sometimes the ground mass is glassy, with dark trichites and microliths. The felspar is probably labradorite, often contains minute particles of glass, and may be studded with apatite. The augite is usually fractured, as in the diabases ; the apparent fracturing being due to included triclinic felspar. Olivine is rarely recognisable. Dr. Geikie has adduced evidence to show that the felspar crystals were already formed when the rock was in a fluid state.

The basalts, as usual, are the finer-grained dolerites, and are well seen in the rocks of Craiglockhart Hill and Long Row, near Edinburgh. The augite crystals are nearly unbroken ; olivine is almost always visible. Octahedrons of magnetite occur, but apatite needles are rare. At Mid-Tartraven in Linlithgowshire the olivine crystals abound in magnetite.

Pikrite.—Another group of rocks characterised as serpentine-olivine is represented by pikrite. In Scotland it is only known from Blackburn, near Bathgate, and the island of Inchcolm. It formed a true lava-sheet at Blackburn, but appears to be intrusive at Inchcolm. It is blackish-green, and contains olivine and augite, with brown biotite, and has the crystals often united together with serpentine.

Pikrite is a rare rock in Britain. It occurs *in situ* at Little Knott, east of Bassenthwaite.[1] Boulders of a similar rock have been described by Professor Bonney from near Pen-y-Carnisiog in Anglesey. This, like the pikrites of Fifeshire, described by Professor Archibald Geikie,[2] is characterised by a ground mass formed of small tufts of needle or blade-shaped crystals of hornblende, which from its optical properties resembles actinolite, and is not regarded as an original constituent of the rock. Secondly, there are both small and large green-coloured and strongly dichroic hornblende crystals. Augite is found in colourless grains and crystals, which are usually embedded in a chloritic mineral. Opacite and rounded grains resembling magnetite occur with many pseudomorphic constituents, which Professor Bonney believes to indicate the former presence of olivine. The larger hornblende crystals are of a brown colour, and are believed to have been originally augite. In the Fifeshire rocks olivine still remains as the dominant mineral well preserved.

Porphyrites.—Many of the rocks which were formerly mapped as felstones and porphyrites, Professor Geikie groups as felspar magnetites, and distinguishes from felstones under the name porphyrites. They agree with the Old Red Sandstone lavas, and are among the thickest and most widespread of the Carboniferous period, extending through Berwick, Roxburgh, and Dumfries, and through the Garlton Hills of Haddington, are seen at Calton Hill and Arthur's Seat, and range through Dumbartonshire, Renfrewshire, and the north of Ayr-

[1] Bonney on Hornblende Pikrite, Q. J. G. S., vol. xxxvii. p. 137.

[2] Trans. Roy. Soc. Edin., vol. xxix.

shire. The rock has a dull, coarse-grained porphyry base, in which are scattered triclinic felspar and sometimes orthoclase. The base varies from dark chocolate or purple to pale yellow or white, and may be greenish or bluish. It is frequently amygdaloidal. Porphyrites are relatively less heavy than basalts. The microscope shows the ground mass to be a clear colourless felspar, so that about nine-tenths of a typical porphyrite is felspathic. Next in abundance are octahedra of magnetite. Augite is not always present.

Felstones.—Finally, there are the orthoclase felspar rocks, termed felstones. They consist of a finely granular felsitic ground mass, with grains of quartz and crystals of orthoclase. Felstone is well seen on the shore at Largo in Fife, where it forms a volcanic neck. It is also seen as a yellow quartz felsite among the Campsie Fells stretching into Ayrshire; this rock was originally a rhyolite.[1]

Permian Volcanoes.

Permian Volcanoes of Dumfries.—In the northern half of the Thornhill basin in Dumfriesshire, the lower part of the Permian series consists of a succession of interstratified beds of porphyrite, which are lava-flows associated with beds of tuff. From Nether Dalbean the rock forms swelling slopes with occasional hillocks, which extend southward. A large mass of it covers the carboniferous rocks at Norton Castle, and it is seen to the south-east of Townfoot; on the west it occurs in the bed of the Nith. The porphyrite is identical with that of the Permian volcanic rocks of Ayrshire, varying from a fine-grained compact rock to a dull earthly scoriaceous rock. It consists of plagioclase felspar with much hematite, which often replaces augite or other minerals. Most of the rock is much decomposed; it is best seen at the bend of the Nith between Drumlanrigg and Carron Ridge. Another grand section occurs half-way between Gatelaw Bridge and Kettleton Bridge on the left bank of Campsie Water. These rocks rest upon the Carboniferous series, and are covered by the usual brick-red Permian sandstones. Carron Water is the centre of the volcanic Permian district of Thornhill, and here some of the blocks of agglomerate weigh half a ton or more. In Garroch Water a thin bed of ashy breccia divides these Permian rocks from the Carboniferous series.[2]

Permian Volcanoes of Ayrshire.—In Ayrshire many necks of volcanic agglomerate mark the site of ancient volcanoes. The coal-workings have shown that they descend vertically, and destroy the coal-seams for some distance around them. Five such necks are seen to the south-east of Symington, three to the east of Irvine, three more near Stevenstone, besides many others. Several of these necks occur along a line of fault.[3]

[1] Geikie: "Carboniferous Volcanic Rocks of the Firth of Forth," Trans. Roy. Soc. Edin., vol. xxix. p. 437. See also Mem. Geol. Surv. East Lothian, 1866; Geol. Edinburgh, 1861; and East Berwickshire, 1863.

[2] Arch. Geikie: Mem. Geol. Surv. Scotland, Explanation Sheet 9, 1877.

[3] Mem. Geol. Surv. Scotland, Explanation Sheet 22, Arch. Geikie.

Serpentine.

Serpentine of the Lizard.—The serpentine district of the Lizard is a wild moorland plateau furrowed by gullies and small coves with cliffs, which often rise vertically for from one to two hundred feet.

In this area, besides serpentine, the rocks shown are gabbro and hornblende schist, with some granite and dolerite. The first junction of the serpentine on the west coast is seen near Polpoer. On the north of a little chine the brecciated rock is all serpentine, on the south it is hornblende schist. The serpentine is intrusive; near by other masses of hornblende schist are included in the serpentine, which is sometimes dull-red, mottled with a dull-green mineral and occasional flakes of bronzite. The different varieties which it exhibits are all the result of decomposition. The rock is cut through by veins of granite in many places, and at the contact the serpentine is altered. At Cadgwith the rock is black; it contains, according to Mr. Hudleston, 36 per cent. of magnesia, 38 per cent. of silica, 12 per cent. of water, 8 per cent. of iron, and 2 per cent. of lime in the matrix freed from crystals.

On the east coast the exposures are even more complicated than on the west, the hornblende schist being frequently included in the serpentine, while the latter rock is cut by gabbro veins and by granite. The gabbro is of two ages; the older variety has a dull-red ground mass, with greyish-white felspar and small crystals of diallage, and may easily be mistaken for serpentine. The newer gabbro is coarser in texture and more decomposed. Professor Bonney believes the intrusion of the serpentine took place after the metamorphism of the hornblende schist, and that the metamorphism of the serpentine was complete before the intrusion of the gabbros and hornblendic dolerites which are found on the east coast.[1]

The Lizard serpentine contains olivine, enstatite, olive green with a metallic lustre, diallage, hornblende, augite, chrysolite, picotite, besides magnetite, occasionally a little felspar, and products of decomposition, such as steatite. It closely resembles lherzolite, and is regarded as an altered peridotite intrusive in hornblende schist.[2]

Among the localities described are Coverack Cove, Mullion Cove, Gue Graze, Lower Pradanack Quarry, Hill Quarry, Helston Road, Goomhilly Downs, Kynance Cove, George Cove, Carn Sparnack, near Cadgwith, and Balk.

Serpentine of Anglesea.—Serpentine occurs at several localities in Anglesea and in Holyhead. It is found in a bluish or greenish schist, which is greatly crumpled near Ty Newydd, and is itself cut through by gabbro, which sometimes has a serpentinous aspect. Sometimes the serpentine is reddish, brecciated, and veined with calcite. A larger mass of serpentine occurs near Rhoseolyn, at the

[1] Bonney: Q. J. G. S., vol. xxxiii. p. 884.
[2] Q. J. G. S., vol. xxxix. p. 1.

south end of Holyhead Island. Here dark-green serpentine is associated with gabbro. The serpentine is shattered and slickensided, and is in contact with ophi-calcite, which is a breccia of dark serpentine cemented by calcite infiltrated from the overlying Carboniferous limestone. Under the microscope the serpentines give evidence of being altered olivine rocks like Dunite, with various other associated minerals now decomposed and replaced by ill-preserved pseudomorphs, so that it is classed by Professor Bonney as an altered peridotite. The rock at Porthdinlleyn in Caernarvonshire, formerly regarded as serpentine, is classed by Professor Bonney as a diabase tuff on the evidence of its microscopic structure.[1]

Serpentine of Ayrshire.—On the coast of Ayrshire serpentines are exhibited at Lendalfoot and at other points between Balcreuchan Port and Pinbane Hill. They are also seen at Balhamie Hill, near Colmonell. In the latter exposure the rock has a rhomboidal jointing, the joints coated with greenish or whitish steatite. It is full of crystals of glittering bronzite or some similar mineral. The olivine is completely converted into serpentine, and the rock is regarded by Professor Bonney as an altered olivine enstatite which contains 38 per cent. of silica, 35 per cent. of magnesia, and 4 per cent. of alumina. The associated dolerite rocks are particularly interesting, some of them having the aspect of being metamorphosed sediments, while others have an igneous aspect. Some writers have regarded them as diorites, but they contain plagioclase and augite. There are also gabbros of two ages, one similar to the gabbro of the Lizard, very rich in diallage, so as to be almost a mass of diallage crystals. The serpentine is older than the diallage rock and gabbro, and is intruded into rocks which were regarded by Murchison as of Bala age.[2]

Serpentine dykes of Carboniferous age occur in Forfarshire.

These serpentines, like those of Portsoy in Banffshire,[3] are modified volcanic rocks, though really to be classed as metamorphic rocks. Other serpentines appear to be derived from sedimentary rocks, metamorphosed in the usual way. (See Heddle, T.R.S., Edin., vol. xxviii.)

Secondary Volcanic Rocks.

Sir Henry De la Beche, nearly fifty years ago, gave an excellent account of the felsitic rocks associated with the lower part of the New Red Sandstone in Devonshire. He states that the section at Washfield near Tiverton gave the best evidence of a volcanic eruption, the lava being covered by detritus containing angular volcanic fragments which sometimes weigh a ton. These fragments contained quartz and large crystals of glassy felspar;[4] and nearly thirty years later Mr. W. Vicary, F.G.S., described all the volcanic rocks near Exeter in more detail.[5] There are no more interesting volcanic rocks in Britain.

[1] Bonney: "Serpentine of Anglesey," Q. J. G. S., vol. xxxvii. p. 40.
[2] Bonney: "On Serpentine of Ayrshire Coast," Q. J. G. S., November 1878.
[3] See also post, p. 388.
[4] Proc. Geol. Soc., vol. ii., 1835, p. 196.
[5] "Report and Transactions of the Devonshire Association for the Advance of Science, Literature, and Art," part iv., 1865.

Killerton Park has the aspect of a great volcanic centre formed of compact dark micaceous lava, vesicular in the higher portions, becoming red, scoriaceous, and ashy in the neighbouring quarries at Budlake and Silverton. The compact rock near Tiverton at Holmead, almost like a mica schist for its abundance of mica, similarly corresponds to the scoriaceous and ashy beds which extend from Washfield to Loxbeare. The compact lava which forms Knowle Hill may represent the centre from which the porous lavas and ashes of Pocombe and Northernhay flowed. In the Crediton district, Postbury furnishes the compact crystalline rock which thins as it extends to Yeotown, while highly vesicular rocks are met with at and about Spence Combe, often jointed with "mountain cork." As in all similar rocks, the vesicles, now amygdaloidal, are greatly elongated by flowing movement of the rock, so as to often give an aspect of stratification. Other large volcanic masses occur near Haldan and at North Tawton. Their colour is dark red or purple black. They vary in mineral composition; are remarkable for a clear felspar, which occurs in porphyritic masses in the rock at Knowle and many other places; and this is associated with plagioclase, with a frequent abundance of brown mica, some orthoclase, potash mica, some brown hornblende, and much hematite. Hence some of these rocks seem to be related to the minettes. Some Exeter rocks are referred to by Professor Bonney as basalts.

Tertiary Volcanic Rocks.

The British volcanic rocks of Tertiary age cover two distinct areas; first, the large district in the N.E. of Ireland extending round Lough Neagh, which comprises nearly the whole of Antrim and the adjacent part of Londonderry; and, secondly, the chain of the Inner Hebrides, including Mull, Rum, Eigg, Canna, Muck, and three-fourths of Skye. This line of old volcanic activity extends N. to the Shiant Islands, and appears again in the Faroe Isles, before terminating in the older volcanic districts of Iceland. Hence, the tertiary volcanoes of Britain are the southern end of a band nearly 800 miles long, which is still active at its northern extremity. The rocks in Ireland and in Scotland include acidic series as well as basic series. The basic series of Scotland is demonstrably the younger; but in Ireland the rocks which have been identified as trachyte and rhyolite appear to be older than the basalts.

Acidic Rocks of the North of Ireland.—The acidic rocks of the North of Ireland have hardly received the attention which their importance demands. They occur in many places, especially near Tardree, in the neighbourhood of Templepatrick, near Broughshane; and at Ballyknock, south-west of Hillsborough. Some of these rhyolites are regularly bedded, and intrusive in the dolerites, and therefore younger than the dolerites. The analysis by Mr. Hardman does not differ from the composition of typical rhyolites of Germany.

	Rhyolite, Tardree, near Antrim.
Silica	76.96
Alumina	5.10
Peroxide of iron	2.34
Lime	7.06
Magnesia	0.30
Soda	1.82
Potash	4.26
Water	2.10

Basalts of North of Ireland.—The coast between Belfast Lough and Lough Foyle is one boundary of a large tract reaching westward to Lough Neagh, and including the river Ban, which is almost wholly occupied on the surface by basaltic rocks, rising at intervals to eminences of 1320, 1820, 1864 feet above the sea. Under this immense overlying mass of basalt are found several members of the secondary series of strata not known elsewhere in Ireland. 1. Chalk, agreeing with the lower beds of the English series. 2. Mullattoe, an Irish name for the Hibernian Greensand of geologists. 3. Lias limestone (without any other rock of the oolitic system). 4. Beds of red marl, gypsum, and salt, resting on variegated sandstone. 5. At the north-eastern and south-eastern extremity, coal-measures, consisting of red sandstones and shales with inferior coal, appear below all the other strata. The mulattoe and lias are often wanting in the section. The superincumbent basalt is estimated to have an average thickness of 545 feet (in Benyavenagh it is 900 feet, in Knochlead 980 feet), and its superficial extent 800 square miles.[1]

The immense mass of doleritic rocks in this district exhibits, besides basalt, which is the most abundant material, several other varieties of rock. Near the Causeway, the cliffs consist of alternating basalt and red ochre, in the following order downwards:—

1. Basalt rudely columnar, 60 feet.
2. Red ochre or bole, 9 feet.
3. Basalt irregularly prismatic, 60 feet.
4. Columnar basalt, 7 feet.
5. Intermediate between bole and basalt, 8 feet.
6. Coarsely columnar basalt, 10 feet.
7. Columnar basalt, the upper range of pillars at Bengore Head, 54 feet.
8. Irregularly prismatic basalt, 54 feet. In this bed the wacke and wood coal of Port Noffer are situated.
9. Columnar basalt, forming the Causeway by its intersection with the plane of the sea, 44 feet.
10. Bole or red ochre, 22 feet.

11, 12, 13. Tabular basalt, divided by thin seams of bole, 80 feet.

14, 15, 16. Tabular basalt, occasionally containing zeolites, 80 feet.

[1] See also Lee's Note-Book of a Geologist.

Contact Metamorphism by Basalt.—The stratified rocks in contact with the trap have undergone remarkable changes in several localities.

At Portrush, the lava, a rudely prismatic dolerite, overlies and perhaps alternates with a flinty slate, which contains numerous impressions of Ammonites, belonging to the Lias shales. This transformation of Lias shale reminds us of the more extensive phenomena of the same kind in Savoy. Most of the alterations of stratified rocks on this coast are produced by basaltic dykes, which divide both the overlying masses of trap and the subjacent strata. At the foot of the hill called Lurgethan, basaltic dykes traverse the red sandstone conglomerate, which is altered near the contact so as to resemble compact hornstone.

The coal-measures, underlying the basalt of Fairhead, are crossed by dykes which have changed the ordinary shale into flinty slate,

Fig. 65.—The Giant's Causeway.

hardened and pyritised the sandstone for 15 yards, and converted the coal to cinder. The chalk is traversed by many dykes, and is converted into a real marble for 10 feet or more from the contact with the basalt.

The effects in approaching the contact are first a yellowish tinge of colour, then a bluish-grey colour and compact texture, then a fine-grained arenaceous aspect, next a saccharoid granulation, and finally, close to the dyke, the chalk is altered to a dark-brown crystalline limestone, with flaky crystals as large as those in limestone. The flints in the altered chalk assume a grey-yellowish colour; the altered chalk is highly phosphorescent when heated. Examples are seen near Belfast, at Glenarm, in Rathlin, and other places. Near the top of the chalk which crowns the cliffs of Murloch Bay is an interposed bed of wacke 5 or 6 feet thick.[1]

Volcanic Mud Streams of the Hebrides.—Before the volcanic

[1] Conybeare, Trans. Geol. Soc., vol. iii.

eruptions occurred in this land of the Inner Hebrides the whole country appears to have been elevated out of the sea. The present Duke of Argyll was the first to demonstrate the condition of the old land by describing the section at Ardtun Head on the northern shore of the Ross of Mull. There, near the base of the cliff, preserved in a mud stream, formed by rain washing down the fine volcanic ashes, and afterwards sealed down by thick beds of basalt, are the leaves of species of Platanus, and the large conifer Sequoia langsdorfii, which occurs in the London Clay, and in the older tertiary deposits of Greenland, Spitzbergen, Iceland, and Central Europe.

In Ireland a more abundant flora has been described by Mr. W. H. Baily, from volcanic-mud beds beneath the basalt at Ballipallidy. The volcanic activity of this region probably extended over a prolonged period of time, for several leaf-beds in the island of Mull are separated from each other by ashes, indicating that the eruptions were intermittent, as they are in Etna and Vesuvius.

The old volcanoes of the Inner Hebrides are now known from nothing but skeletons of the cones. The loose ashes which formed the upper parts of mountains have been worn away, or blown away, sometimes to the thickness of 5000 feet, and nothing remains where the volcanoes stood but cores of granite or gabbro which formed the matter erupted into the base or the throat of a volcano from which the surrounding basalts or felstone lavas were ejected.

The Mull Volcano.—One of the most interesting of the skeleton volcanoes forms the S.E. of the island of Mull. Previous to the outburst the Mull country was formed of Upper Cambrian Rocks like those seen on the opposite coast of Morvern. Through these rocks, granite of Primary age rises to form the south-west of the island. And resting on the Cambrian Mica-schist, secondary rocks are seen beneath the tertiary lavas at many places round the coast.

Professor Judd [1] fixes the building of the old volcano as dating from the Lower Tertiary period. The central mass consists of granite, but all round the granite is the less crystalline rock called felsite, which granite becomes when it cools rapidly. The altered rhyolites or felsites are covered by beds of felsitic ashes and agglomerates ejected into the air and subsequently consolidated by the action of rain. After a period of activity of unknown duration the volcanic fires of Ben More died away, and the volcano was probably denuded, so that most of the ashes were washed away and the granites and felsites were exposed on its surface. After this interval the volcanic fires broke out again, but brought to the surface another kind of rock which consolidated to form a central core of gabbro [2] or hypersthenite. This gabbro burst through the granite and has sent sheets of fluid rock into the granite in every direction, forming dykes. Ashes were once more thrown out, and some of those basic agglomerates still

[1] Q. J. G. S., vol. xxx.

[2] The name gabbro is a convenient term which may be used in a generic sense for this rock. There is no diallage in it, but it does not contain true hypersthene.

remain resting upon the older acidic agglomerates, and penetrated by dykes of gabbro. When gabbro is poured out as lava it becomes basalt and dolerite; and floods of basalt extend round Ben More in unbroken sheets. They cover the whole of the North of Mull, and lap along the west coast of Morvern. Indications of their extent are seen in the now isolated patches which form Ulva, Staffa, the Treshnish Islands, and the rock covering the Ross of Mull, but the lava extended much beyond its present limits. Ben Yattan shows that it flowed far into Morvern, while southward it may have extended into the Firth of Lorne. The circumference of the base of this volcano could not have been less than 40 miles, and judging from the proportions of Etna, its height may have been 14,000 feet. Like Etna the old Mull volcano appears to have been covered with small cones towards the close of the second period of its activity. One of these minor cones, or puys, called Ben Sarsta, rises to a height of between 800 or 900 feet. It is situate behind Tobermory, and consists of a central core of gabbro, surrounded by basalt or dolerite which is altered by contact with the central intrusive mass. This gabbro may well have been the site of the old crater, and in its centre is a small lake. The country round is so covered with bog that neither the lavas nor ashes poured out from this little cone can be distinguished, even if they escaped the denudation under which the great volcano suffered. The central mountain mass of Mull as it is now left has a diameter of 12 miles, and consists of peaks which rise to a height of 2000 to 3000 feet, the highest being Ben More.

Fig. 66.—Fingal's Cave (Staffa).

Staffa.—The cave of Staffa is excavated in vertical prisms of basalt, between rows of which the eye rests on the distant view of Iona. Over the cave the basalt is in smaller prisms, lying obliquely.

Ardnamurchan. — Another great volcano existed in the peninsula of Ardnamurchan. The evidences of its activity are not so clear as those seen in Mull. The whole of the S.W. of the peninsula consists of varieties of gabbro which form wild and barren mountains. On the east the gabbro graduates into dolerite. These rocks are similar to those of Mull, and similarly rest upon and break through a series of acidic lavas. The peak of Meal-nan-Con and the neighbouring heights to the S.W. are formed by intrusive felsite, which, like that of Mull, passes into granite. It is penetrated on the east and south by sheets and veins of newer amygdaloidal felstone, which are interstratified with beds of ashes and scoriæ, full of fragments of the primary and secondary rocks, through which the volcano of Ardnamurchan pierced.

Here, as in Mull, subordinate volcanic cones of later date appear

to have been formed on the flanks of the great volcano. The highest mountain in Ardnamurchan is one of these. It rises to a height of 1759 feet, and is known as Ben Shiant. It consists of a succession of grassy slopes formed of the softer and less compact rocks, which rest upon columnar lava which terminates its slope in a spur. Ben Shiant rises at the junction of the felspathic and basaltic lavas; its rocks contain glassy felspar and sometimes include porphyritic pitchstones and rocks like compact felstones. They are referred to the augite andesites by Professor Judd.

The Island of Rum is a third volcano. Around it lie the smaller islands of Canna, Eigg, and Muck, which are portions of lava sheets more or less interstratified with sedimentary deposits. They accumulated gradually, and helped to mark the distance from which the lavas from Rum extended. The foundation of the island of Rum is a mass of Cambrian sandstone with overlying highly metamorphosed rocks, and far away from the lavas the old strata present their normal characters and are free from intrusive dykes. A number of peaks which consist of gabbro rise to a height of about 2500 feet, piercing through the stratified formations. To the east of the gabbro heights is the older mountain of Oreval, which does not rise so high and is a core of granite. Dykes and veins of gabbro almost innumerable penetrate the felsites and granites of Rum; and, therefore, show that the basic lavas were thrown out subsequently. The ashes ejected from the Rum volcano have nearly all been swept away by processes of denudation, though some patches of felsitic ash still remain preserved by coverings of felstone.

The Island of Eigg has been described in detail by Professor Archibald Geikie, F.R.S. It is about five miles long, from one and a half to three and a half miles broad, and attains a height of 1300 feet. It is an isolated part of a great basaltic plateau, and is so tilted that while it is a thousand feet high at the north, it slopes gently to the south. The volcanic rocks rest unconformably upon estuarine and fresh-water shales and limestones of jurassic age, which have some marine beds at the top similar to the rocks seen in Raasay. The volcanic rocks covering those beds are a succession of dolerites and tuffs, which vary in thickness from a few feet to fifty or sixty feet, and have an aggregate thickness of eleven hundred feet. They vary in character, being sometimes amorphous and amygdaloidal, and sometimes characterised by columnar structure, which may be radiating.

Where the rock is amygdaloidal it is largely infiltrated with quartz and chalcedony, calc spar and stilbite. There is a comparative absence of tuffs and agglomerate in the Tertiary period, as compared with their abundance in the Primary era; but in Eigg many examples occur of breccias interstratified with the dolerite, though they are never thick. As is usual in volcanic districts, intrusive bosses, sheets, dykes, and veins intersect both the underlying oolitic strata and the volcanic rocks. One of these Professor Geikie describes as a quartz felsite, forming a cliff two hundred feet high at

the north end of the island; it is sometimes columnar, and of a pale-grey colour resembling the fine-grained quartz porphyries of Skye and Raasay. One or two other masses of felstones occur in the island. The Scur of Eigg is an elevated ridge two and a quarter miles long, and rising three hundred to four hundred feet above the basalt plateau. It consists of pitchstone and felstone, the former dark-coloured and columnar. The porphyry is grey and interbedded in the pitchstone. Under the microscope the base of this rock is glassy or granular with crystals of orthoclase which are sometimes a quarter of an inch long. The eruption of the pitchstone is considered to have been long subsequent to the eruption of the basalt, and the Scur of Eigg was formerly a river valley in which gravels and drift-wood were buried under the products of successive volcanic eruptions. Subsequent denudation has reduced Eigg to much the same condition as the fragments of the older basaltic plateau of the Auvergne.[1]

Skye.—A volcano which was probable larger than any of the others was situate in the south of Skye. The intrusive igneous rocks burst through strata of Cambrian, Liassic, and Oolitic age, and often transmute the lias into white granular and compact limestone at the junction. The great central granite mass of the Red Mountains, remarkable for their smooth contours, reaches a height of 2670 feet in the pyramidal peak of Ben Glamaig. The granite gradually changes at the circumference into felsites, and is pierced by contemporary veins of the same rock. As in the associated volcanoes, this granite is the core of the older or acidic cone. The later eruption formed the wild hills of gabbro, jagged in outline, which are known as the Cuchullin Hills and Ben Blabheinn, both more than 3000 feet high. On passing outward from the central cores of gabbro, with its large metallic bronzy crystals like hypersthene embedded in the grey labradorite, the rock passes insensibly, first into dolorite, and then into the finer-grained basalt. Patches remain of the old agglomerates and deposits of volcanic ash, mostly mingled with felstone lavas. They are well seen in the hill on the south of Ben Dearg; and in the island of Scalpa they lie on Primary and Secondary strata. The basalt was remarkably fluid, and extended from the Cuchullin Hills in every direction. Much of it may be now covered by the sea, but large fragments stretch to the north-west and north, and form the peninsulas of Skye known as Trotternish, Vaternish, Duirinish, and Minginish. In the island of Raasay an outlier of basalt forms the hill of Dun Can. This volcano of Skye may perhaps have had its principal crater in Loch Coruisk, which is a deep and desolated amphitheatre in the gabbro.

Professor Judd has suggested that the remote island of St. Kilda is an extinct volcano now represented by cores. M'Culloch describes the eastern part as of granite, and the west as of gabbro, with the hills surrounded by basalt.[2]

[1] Arch. Geikie, Q. J. G. S., vol. xxvii. p. 285.
[2] Judd, Q. J. G. S., vol. xxx. p. 255.

CHAPTER XIX.

CONCOMITANTS AND RESULTS OF VOLCANIC ENERGY.

Besides the igneous phenomena already described, there are some other subjects, more or less associated with the geological history of the earth and the reaction of the interior on the surface, which may be termed concomitants of volcanic action. Among such are the upheaval and depression of land; breaks in the succession of strata, which result from changes in relative level of land and water; the undulatory movements of earthquakes; faults; and the intrusion of igneous matter into rocks in the form of dykes. It may be that such phenomena are not always directly connected with volcanic eruptions, but no broad distinction can be drawn between those internal movements in the earth which crumple strata, upheave mountains, raise and depress continents, on the one hand, and the formation of fractures through the rocks, by which vent is given on the surface to the heated materials beneath, since both are consequences of contractions of the earth's crust. Hence we supplement the geological part of volcanic history with the following considerations.

Earthquakes.

The study of earthquakes is the science of Seismology, which endeavours to trace the history and explain the origin of vibrations of the earth's crust.

Dr. Daubeny's Views.—Dr. Daubeny regarded the primary shock of an earthquake as the result of local volcanic excitement, evidence of the accumulation and elastic pressure of imprisoned gases; and the propagation of the motion was attributed to wave-like vibration in the mass of the rocks.

Fissures in the rocks are occasioned by, and are the evidence of, earlier convulsive movements. If we seek the cause of them, we certainly find the greater part of the necessary evidence in the innumerable fractures and flexures of the earth's crust, of every geological date, by which extraordinary disturbances of the strata have happened; for these very frequently occur in large areas, where no other evidence of contemporaneous volcanic excitement can be discovered. It follows obviously that many movements of the earth's crust have been excited without the immediately preceding or coincident local agency of volcanoes, as though all the *differential* effects of volcanoes could be *integrated* into one energetic reaction of the interior against the cooled and consolidated exterior crust.[1]

[1] Humboldt's definition of volcanic agency in "Kosmos" contains this view.

Darwin's Views.—According to the comprehensive idea of Darwin, earthquakes and volcanic eruptions originate in some local fracture and displacement of the bed of the neighbouring ocean; the volcanic effect spreads as far as the subterranean sea of molten rock extends, but is excited to violence at one or more points, the most favourably circumstanced at the time; the convulsive movement is propagated through the solid and liquid contents of the crust of the earth, as far as the nature of these materials and the force of the blow permit. It is important to remark that a blow is struck—the earthquake is the evidence—and this can only mean some rending of the solid crust of the earth. Thus a convulsion seems the necessary precursor of the earthquake; and to allow of the movement traversing whole continents, we must suppose the blow to be given at a considerable depth, expressed in miles, below the surface.[1]

Michell[2] entertained the idea that the sheet of rocks constituting what we know of the crust of the earth was flexible enough to bend to the agitation of an interior liquid ocean of melted rock. The earthquake in this view is a wave in the rocks representing a tide in the subjacent fluid.

Rogers[3] supposed waves of this kind, moving parallel to certain axes, to be effective in permanently raising the ground; and attributes to such an agency in early geological periods the formation of the anticlinal and synclinal hollows parallel to the Appalachian chain.

Mallet's Views.—Mallet,[4] however, both by reasoning and experiment, has shown that the earthquake movement is a wave of elastic compression, whose rate of movement varies according to the elasticity of the medium and the continuity of rock masses. There is one rate of movement for the sea, another for the land; one rate for solid granite, another for broken granite, another for loose sand. This movement near the surface is far less rapid than the elasticity of the media might lead us to expect; a circumstance dependent on the many fissures of the rock, at each of which discontinuity and loss of motion are occasioned.

Velocity of Earthquake Waves.—The actual velocities of some earthquake movements have been approximately ascertained as under in a line directly across the wave :—

		Miles per Minute.	Authority.
Conception, earthquake,	1835	30	Rogers, Rep. to Brit. Assoc. 1843.
Guadaloupe,	1843	27	Do. do.

The Conception earthquake had its crest directed N.N.E. from the western border of Alabama to Cincinnati, a distance of 500 miles. On this line it was felt simultaneously. The motion was to the E.S.E., and was felt at successive times simultaneously on lines directed to the N.N.E. If a measure of velocity were taken on the

[1] Stukeley assigned the improbable depth of 200 miles for the forces of an earthquake in Asia Minor, A.D. 17, which embraced a circle of 300 miles in diameter.

[2] Phil. Trans., 1760.

[3] Brit. Assoc. Reports, 1843.

[4] Mem. Royal Irish Acad., 1846; Brit. Assoc. Reports, 1850, et seq. ann.

N.N.E. line, it would appear infinite; on the E.S.E. line, 30 miles a minute; on intermediate courses, intermediate velocities. The *apparent* velocity of the wave at the surface will be greatest near the point vertically situated over the disturbance.[1]

Mr. Mallet,[2] by careful experiments on the sands at Kingstown, and in the granite rocks at Dalkey, obtained velocities of wave transit as under :—

	Feet per Second.	Miles per Hour.
Loose sand, Killiney	825	9½
Solid granite, Dalkey	1,306	15
Fissured granite, do.	1,665	19

The velocity at the surface may be in these cases somewhat less than that of sound in air, but is far less than was expected by Mr. Mallet from his knowledge of the elasticity of stony media. To judge by experiments on their elasticity, we might expect the sound wave to travel—

	Feet in a Second.		Feet in a Second.
In air	1,140	In primary limestone	6,696
,, water	4,700	,, carboniferous limestone	7,075
,, lias	3,640	,, hard slate	12,757
,, coal sandstone	5,248	,, granite perhaps still higher rate.	
,, oolite	5,723		

Professor Milne finds that in Japan different earthquakes travel with different velocities, and that the velocity of a wave decreases as it travels. In 1881, earthquakes between Tokio and Yokohama moved at rates per second of 4500 feet, 3900 feet, 1900 feet, 1400 feet, 2454 feet, and 2200 feet.

Depths and Origin of Earthquakes.—According to Mallet, the depth of the point where the blow or concussion which is the origin of earthquake movements take place may be as far down below the surface as the versed sine of the arc cut off by the extreme points of the space subject to tremor. In some cases this passes very deeply into the earth.

Origin of Earthquakes.—Taking into account all the phenomena of earthquakes, Mallet admits for consideration the following modes of origin of the impulse :[3]—

(1.) The operation of steam extricated by cooling from the spheroidal state.

(2.) Evolution of steam through fissures, and its irregular condensation under pressure of sea-water.

(3.) Recoil from volcanic explosions.

(4.) Great fractures and dislocations in the earth's crust, suddenly produced by pressure or contraction in any direction.

Earthquake Motion.—The actual movement of the ground, says Professor Milne, is sometimes 8 millimetres, but often under 1 millimetre; there are seldom more than two or three vibrations a second. The motion of the ground towards the origin of the disturbance is usually much greater than the motion away from it.

Professor Ewing of Tokio finds that in almost every instance the

[1] Hopkins, Brit. Assoc. Reports, 1847. [2] Mallet, Rep. to Brit. Assoc. 1851–52.
[3] Reports of Brit. Assoc., 1850.

motion of the ground begins very gradually, and it does not reach its maximum for some seconds. An earthquake consists of many successive movements, among which no single large movement stands out prominently from the rest. The disturbance ends more gradually than it begins. The area affected, duration and direction of movement are very irregular and variable during the same earthquake. Frequently the beginning of visible motion consists in a tremor of short-period waves, about five to the second, followed by the principal movements of one or two waves to the second.[1]

Distribution of Earthquakes.—British earthquakes are always slight; one-third of all that are known are recorded from the county of Perth, and most of the others are also Scotch.[2] In Europe earthquakes are common in all the regions of active volcanoes; and they have especially disturbed Calabria, the country about the mouth of the Tagus, Agram, and several of the Greek islands, like Chios. Many districts which experience earthquakes are free from volcanoes, though the most violent earthquakes occur in volcanic regions. The destructive earthquakes of Asia Minor and Syria are connected with regions where volcanic action has become extinct; but in South America earthquakes are frequently connected with outbursts of volcanoes along the line of the Andes. The ground disturbed by an earthquake as frequently sinks as rises; and there can be no doubt that the fractures produced by undulation of the rocks, which must develop the character of master-joints, are favourable to dislocation. The movements rarely last more than a minute, and frequently only for a fraction of a minute, though one at Tokio lasted four and a half minutes. The areas over which the disturbance extends are extremely variable, the most extraordinary record being that of the Lisbon earthquake of the 1st of November 1755, which affected the North of Africa and Western Europe, and appears to have crossed the Atlantic and travelled to the valley of the Mississippi.

Effects of Earthquakes.—Besides the production of cracks in buildings in the lines of wave motion, tangents to which pass through the centre of disturbance, we may cite as among the best-known permanent effects of earthquakes the formation of the Ran of Katch in 1819; the uplifting of the shore of Cook Straits ten feet in 1855; and the well-known elevation of the Chili coast recorded by Darwin in the "Voyage of the Beagle."

Causes of Earthquakes.—Earthquake action has sometimes been connected with variation in atmospheric pressure, and with the attraction of the sun and moon. Thus earthquakes are more numerous in mountain regions, like the Alps, than in lower regions. The circumstance that they are most numerous in winter would apparently indicate that the radiation of earth's solar heat in winter causes contraction of the rocks, resulting in dislocations which produce perceptible vibra-

[1] Memoirs of Science Department Tôkiô Daigaku. No. 9, Earthquake Measurement, by J. E. Ewing, 1883.

[2] On the 22d April, 1884, an earthquake of some severity was experienced about Colchester, and felt along a line running N.W. by way of Leicester.

tions of the earth's crust; and a similar conclusion is indicated by the well-known fact that the Swiss earthquakes mostly happen at night. But the great earthquake vibrations, which have been measured to extend to depths which vary from a mile or two down to more than thirty miles, are clearly connected with the great internal earth-movements which are consequences of the contraction of the earth's crust from cooling. And while volcanoes are intelligibly accounted for as distributed in lines of predominate anticlinal folding, we are unable to account for many earthquake phenomena unless they are produced by increased compression in regions of predominant *synclinal* folding. For if the base of a *synclinal* fold is fractured owing to augmented contraction of the rocks, and the fissure is formed at a depth of miles beneath the surface, then the distinction of earthquakes from volcanoes becomes intelligible, and their frequent development in plains and at sea, rather than in mountains, is such as might theoretically have been anticipated from their frequent independence of volcanic outbursts, and the dimensions of the areas affected.

Changes of Level in Land.

On the Elevation and Depression of Land.—Whatever may have been the earth's earliest cosmical relations, it appears first in geological history as *a spheroid of revolution*, whose parts have taken their relative place under the joint influence of gravitation to the centre and rotation on an axis. The density increases toward the centre, the surfaces of equal density are elliptical to the same axis as the external oblately spheroidal surface.

This spheroid cools by radiation; contraction of the whole mass follows, so that the crust is pressed into accommodation with the interior. Thus inequalities of the surface would be occasioned; and from the beginning a continual system of reciprocal depressions and elevations would be established. The consequence would be, that the surface of the spheroid would be wrinkled by folds of elevation and depression, growing more and more deep, and with the progress of time more and more complicated. In remarkable harmony with this view is the well-known fact of the frequency of anticlinal and synclinal and more complicated flexures of the palæozoic strata in all parts of the world, flexures which were often completed before the close of that period.

In later periods of the earth's contraction, local inequalities of consolidation—partly dependent on the earlier flexures, partly produced by the inequality of molecular aggregation, as by the separation of different orders of silicates, calcium sulphate, or magnesian carbonates—may have overcome the phenomenon of reciprocal depression and elevation, and limited the areas in which elevation or depression might take place—and in which one might follow the other—so that the same tract might be alternately raised and depressed.

In nearly all cases depression must be supposed to be real and gradual,—that is to say, part of the earth's surface affected by it must be gradually carried nearer to the centre than it was before; the

elevation may have been in many cases only relative and gradual, but in others real and unequal; that is, the area may have been removed farther from the centre than it was before, by a force of lateral pressure subject to inequality and cessation. In some cases of real depression, and in many more of real elevation over *a limited area*, the solid crust must be supposed to have been intensely folded.

General upward pressure rarely if ever happens; the crust would be *extended*, and beyond a certain strain it would *break*, when the broken parts would slide on one another *so as to occupy a larger area*, and the result would be *faults*. Such conditions are apparently observed in the region of the Rocky Mountains.

In a case of real depression of a given tract, followed after a long interval by elevation, the effects would vary according to the area moved and the vertical range of the motion. If the area were so extensive as to include a larger arc on the earth's surface, the crust would subside into a *smaller area*, and be wrinkled, or otherwise affected by compression and augmented heat. On the re-elevation of such an area, faults would probably be produced; this seems to have been the case in many of our coal-fields, whose flexures are traversed by later faults. If the subsiding area were small or narrow, and the downward movement great, the rocks would sink into a larger area, and faults might be expected. On the re-elevation of such a tract much local disturbance and complicated internal movements among the masses of the rocks would probably follow, and this may have happened in the Belgian and Somersetshire coal-fields.

The influences of these conditions have not yet passed away. Scandinavia is rising and sinking, not in either case on account of volcanic excitement, strictly so called, but by reason of internal changes consequent on slow refrigeration.

Upheaval of Land.—In Smith Sound raised terraces occur at from 32 to 110 feet above high-water mark. Other evidences of rise consist in the existence of ruined houses high above the water, as at Hunde Island. Dr. Kane assumed the upheaval to take place north of latitude 77°, south of which the land is depressed. Over many places in the Arctic lands, as on the summit of the Coxcomb range in Baring Island, shells of living species occur many hundred feet above the sea-level, which would indicate recent upheaval.

On the coast of Norway, Professor Keilhau infers that the whole country from Cape Lindernas to North Cape has been raised in comparatively recent times, the upheaval amounting on the S.E. coast to more than 600 feet. Sir Charles Lyell in 1834 described the raised sea-beaches at Uddevalla, which are 100 feet above the sea, and have barnacles adhering to the gneiss. In 1730 a beach-mark was made in the island of Loeffgrund, near Gefle, in the presence of Linnæus, which in 1839 had been elevated three feet; but farther north, by the mouth of the river Tornea, at the head of the Gulf of Bothnia, the land is rising at the rate of five feet in a century. The waters over which the French expedition measured an arc of the meridian are now replaced by meadows.

Similar evidences of elevation in recent times are found in the Mediterranean. Not only is the shore of Tunis becoming too shallow for the approach of ships, but the coasts of Sicily, Sardinia, and parts of Tuscany tell the same story in the elevation of shell-beds, which sometimes, as in Sardinia, contain pottery at a height of 200 feet above the sea. The shores of the Adriatic, however, are undergoing depression.

Mr. Kinahan, in his "Geology of Ireland," has described numerous raised sea-beaches and sea-margins, and others are well known on the Devonshire coast and in Cornwall, where Mr. Ussher has referred to them at Mount Edgecombe near Plymouth, Looe Island, St. Austell's Bay, Falmouth, south of the river Helford, Coverack Cove, &c., &c.[1]

Depression of Land.—Depression is inseparable from elevation, just as every synclinal fold is a portion of an anticlinal fold. Hence, beyond the geographical limit of upheaval a coast is found to be subsiding, and the regions where this condition is seen are necessarily adjacent to those which are being raised. On the Greenland coast, in Igalliko Fiord, in 1779 a small rocky island was entirely submerged at spring-tides, yet the walls of an old Norse house remained visible. Fifty years later only the ruins rose above the water. In many places farther south, in lat. 62°, 63°, 64°, and 65°, the ruins of dwellings are seen which are overflowed by the tide. The Moravian Mission settlements moved inland the posts on which the large boats are kept. In Disco Bay, Dr. Robert Brown records that a blubber boiling-house was built about eight miles from the shore on an islet, which sunk gradually till the water entered the floor of the house at high tide, when it had to be abandoned.

In the Mediterranean, the standing pillars of the temple of Jupiter Serapis, in the Bay of Baiæ, are an example of the extreme steadiness with which earth-movements both of elevation and depression take place.

But the most striking instances of change of level at the present day are recorded by the phenomena of barrier reefs and atolls.

On our own shores depression is proved by submerged forests, as at Looe, Fowey, Falmouth, Mounts Bay, Padstow in Cornwall, Porlock in West Somerset, and many places in Norfolk, Sussex, &c.

The entire history of the strata is a record of a few grand oscillations of level, from which it has resulted that the same area has been alternately covered by fresh-water deposits accumulated upon land, and marine deposits which were superimposed when the region sunk beneath the sea.

Is Steam a Cause of Upheaval or a Consequence?—It is conceivable that water might be conducted, in consequence of some accident of the earth's crust, to the required contact with the heated rock at some moderate depth below the surface, and thus high-pressure steam be generated and accumulated until disturbance comes. A gaseous force of some kind may be supposed; thus the melted rock is pressed up to the very summits of Teneriffe and the Andes; and masses of stone hurled out of Vesuvius have fallen at a distance of

[1] Geol. Mag., 1879

five or six miles at Pompeii. It is necessary to assume the stone to have been thrown about 7000 feet above the summit of Vesuvius, or more than two miles above the sea, and the force to do this work may be supposed to have been seated one, two, or three miles below. American volcanoes have thrown bombs to far greater distances.

That the steam or gas power, thus estimated for intensity, is also of enormous volume and magnitude, appears from the continuity of some eruptions, the amazing mass of rock which has been ejected, the clouds of ashes, the rapidly formed hills, the land upheaved, and the islands raised. Thus in forty-eight hours the volcanic forces seated about the Lucrine lake raised by showers of ashes a hill called Monte Nuovo, 440 feet high and 841 feet deep in the middle (1538). Skaptar Jokul, or a great Icelandic volcano thus indicated, is reputed to have thrown out three streams of lava, eight miles apart, which covered an area of 1200 square miles; though it has been affirmed that Icelandic records show that the mountain so named has never been in eruption.

The pressure of steam equal to raise felspathic lava five miles high may be called in round numbers 2000 atmospheres, a pressure attempted at the request of the British Association by Mr. Hopkins and Sir W. Fairbairn. These experimentalists accumulated pressures equal to that of the highest mountains—nay, equal to thirty-three miles of water. Such a pressure, unrelieved by volcanic vents, might lift large tracts of solid land.

Probably the western coast of South America, raised in 1822 for 1000 miles in length, and in places for three or four feet, was uplifted less by the explosive power of steam than by the crumpling of the earth's crust, which takes place owing to lateral east-to-west contraction and vertical expansion of the rocks beneath the Andes, consequent upon the formation of a vacuity by the discharge of volcanic products; and elevation in most cases must result in pressure, which increases the heat beneath mountain chains, and thus generates steam.

Hopkins' Theory of Elevation.—Mr. William Hopkins, F.R.S., gave a mathematical form to the experiences of miners and geologists. which had recognised the existence in a limited area of two sets of dislocations placed at right angles to one another, which often yield metallic matters of different kinds. These fractures may depend on one system of movement under that district. Suppose an expansive force gradually augmenting under the whole of a limited tract, and capable of bearing up the whole mass of the strata there. Let these strata be capable of extension, so that they should swell up into an arch, but let their extensibility be limited, so that at last the arch must break. It will depend mainly on the outline or figure of the ground raised what shall be the direction of the fractures. If the area be indefinitely very long as compared to the breadth, and the sides be parallel, there will, in the first place, be one or more fractures parallel to the length of the figure—across the lines of greatest tension—and, secondly, other fractures depending on them at right angles to them. Thus, in the mining districts of Alston Moor, the

north-and-south fractures, parallel to the great Pennine fault, and the east-and-west fractures, at right angles to these, compose a system in accordance with the mechanical theory.

Again, if the force under a given district be determined by any peculiarity of the rocks to a conical elevation, there will be radiating primary fissures and secondary concentric ones. Such a case, perhaps, occurs in the volcanic elevation of Mont Dore. An elliptical elevation would have characters intermediate between the two, and the same district may show traces of one of these superadded to the narrow rectangular elevation first noticed.[1] Such a case occurs in the Weald of Sussex. By cautiously employing this ingenious mode of interpretation, we shall be able to determine, in any given region where the fractures of the strata are well traced, the whole area of the ground subject to any movement at a given time.

It is unnecessary to quote examples in which Mr. Hopkins' views find a useful application. We will only state a single case of the parallelism of trap dykes, which has been furnished by Archdeacon Verschoyle, in the north-west part of Mayo and Sligo.[2] He describes no less than eleven basaltic and amygdaloidal dykes, which, in a space of 11½ miles in breadth, traverse the northern part of the district in a nearly east-and-west direction, and cut through all formations from gneiss to the Carboniferous limestone. One of these dykes he traced between sixty and seventy miles, and believed it might be followed much farther to the eastward. Two of the dykes are crossed by others having a north-and-south direction.

Hopkins on the Elevation of the Weald.—In the large elliptically elevated area of the Weald, 150 miles long from east to west, and 40 miles broad from north to south, between the chalk escarpments, Mr. Hopkins recognises, besides the general broad anticlinal slopes which determine the main features of the district, several lines of flexure and fracture, and anticlinal axes; and he also defines some of those transverse lines of movement, depending on the main axis and boundaries of the district, which are directly deducible from his theory. He combines with the elliptical elevation of the Weald the more elongated system of parallel movements of the Isles of Wight and Purbeck. The remarkable breaks in the bounding chalk ranges which give passage to the rivers flowing from the Wealden northward and southward were supposed to correspond in situation with cross fractures, indicated by theory, and occasionally proved by observation. One considerable decisive and simultaneous movement is appealed to for the dislocations of the elevated mass, and for the production of its main physical features; but there is still a necessity of admitting a slow and gradual continental elevation to account for the denudation of the district.[3] And we shall do well, before accepting the origin of these river valleys in faults, to consider the history of river valleys in the South of Ireland advanced by the late Professor Jukes, F.R.S.,[4] and the application of similar views to the

[1] Camb. Phil. Trans., 1837. [2] Proc. Geol. Soc., 1833.
[3] Geol. Trans., vol. vii. [4] J. B. Jukes, Q. J. G. S., vol. xviii. p. 378.

Wealden district enunciated by Mr. Whitaker,[1] from which it appears that the river valleys are older than the denudation of the Weald.

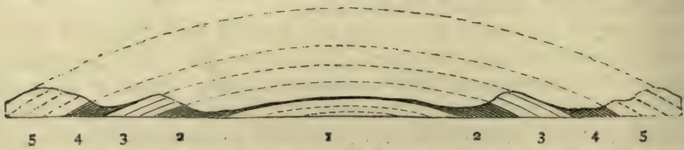


Fig. 67.—General section of the Wealden, showing the probable extent of denudation.

1 Hastings sand. 2 Weald clay. 3 Lower greensand. 4 Gault. 5 Upper greensand and Chalk.

John Phillips' Hypothesis of the Elevation of Land.—Newton supposed the spheroid to be homogeneous; it has been found that this supposition is by no means fitted to fulfil the observed conditions of the problem of the earth's figure. And the irregularities of attraction indicated by the pendulum experiments, and of curvature demontrated by direct meridional measurements, seem to show that the *concentric masses* of the spheroid are *not* of *uniform* density.

This being allowed, there would seem no objection to supposing that the densities along any one *radius* of the spheroid are *variable*, by reason of internal movements among the unequally dense parts of the concentric masses, and this would exactly answer the conditions of the geological problem. For the length of any radius of the heterogeneous spheroid would necessarily vary with the densities; and considering the small proportion of the height of the land above the mean radius of the latitude, it is clear that small internal changes in a length of 4000 miles would easily account for variations on that line to the extent of 1000 feet or yards. This *hypothesis* would give a gradual and prolonged elevation in some parts and corresponding depressions in others; it would not affect in a sensible degree the astronomical elements of the planet, but would change more or less completely its hydrographical boundaries.

This view is an example of speculation which has no sound logical basis, since we know nothing of internal movements in the earth due to variable density. But the hypothesis has some historical interest as a precursor of the modern doctrine of crumpling as the cause of elevation.

Disturbances of the Strata.

Proofs of Dislocation.—When strata, originally level, or nearly so, have been raised to high angles of inclination; when beds, originally continuous, are found to be broken asunder, and their separated portions placed in new relations of position, one portion being raised or depressed, or both deranged; when layers, originally flat, are found to be bent into extraordinary curvatures; the conclusion is inevitable, that contortions, if not convulsions, have happened in the places where such phenomena occur.

[1] Whitaker, Geol. Mag., vol. iv., 1867.

Evidences that Strata were not Deposited in Inclined Layers.—General experience assures us of the fact, that agitated water deposits sediment slowly in the form of strata whose upper surfaces continually tend to become horizontal. This is seen in inundations from a river, in shallow and ruffled lakes, and within the low-water margin of the sea. The form of the bottom influences the horizontality of the upper surfaces of the deposits in such a way that where the bottom is like a pit, the stratified masses above are hollow on the faces; but these effects of the original inequality are rapidly obliterated by successive coats of sediment, all becoming more and more nearly horizontal. In perfectly tranquil water, through which any fine sediment is equally diffused, the depth to which this will cover any part of the bed depends on the depth of the supernatant water, and on the *angle of rest in water* of that kind of sediment. The *angle* of rest *in air* for earthy substances is about 45°. If a river bring sediment into agitated water, deposited strata tend to become horizontal, but with a constant dependence upon the point where the river enters, such that, the quantity of sediment being there always accumulating, a general conical slope therefrom in all directions will modify the horizontality of the strata. Or if a river bring sediment into calm water, or into water suddenly deepening, so that all its lower parts may be considered as calm, the conical slopes from the point where the river enters will be much more abrupt than in the former case, in a certain proportion to the calmness and depth of the water. This is the case in the deep lakes which receive sediment from the torrents of the Alps.

On considering these cases with reference to stratified rocks, it is evident that instances coming within the class of conical deposits radiating round a point can only be of very limited occurrence, not likely to affect a general argument, and are, in fact, almost unknown. The lacustrine deposit of the Weald of Sussex has been regarded by Mr. Topley as an area of seeming upheaval, in which the thinning out of the beds away from the district is a true explanation of their dip.[1] It is very doubtful how far this can be recognised in the thinning out of any marine formation, and certainly it does not apply conspicuously to any class of marine deposits now in progress: at the same time we must admit that, in all cases, the action of the sea grows less and less sensible far from shore where the water deepens, and the sediment brought by rivers and floods must be formed in attenuated masses, thickest towards the shores. This effect will be in exact proportion to the *falling velocity* of the particles in water, so that pebble beaches lie in steeper slopes and cover shorter breadths than sands, while fine clays will spread farther into deeper water. But all these slopes *in water* are very gradual, so that even against the rocky eastern coasts of England, the deep waters have been filled up by sediments, which now assume a gently declining surface under the water, and often only a moderate slope above it.

[1] Topley, Q. J. G. S., vol. xxx. p. 186.

Pebble Beds indicate Upheaval.—When we find traces of a sudden and complete change in the succession of aqueous deposits, so that the quiet deposition of clay or limestone is interrupted by a tumultuous aggregation of pebbles, we know that there has been some agitation of the water. This may have happened either from a periodical or accidental change in the drainage of the neighbouring land, or from some extensive change in the relations of land and sea. The latter interpretation may be adopted if these indications of agitation are very extensive, and if there be proof of local conglomerates following upon local convulsions.

Another indication of some distant convulsion affecting the relations of land and sea seems to be afforded from the occurrence of a bed of marine shells among fresh-water estuary deposits without any local unconformity of stratification; though the alternation of fresh-water and marine conditions in the Lym Fiord in Jutland shows that prevailing winds changing their direction or force may account for some such phenomena.

Method of Fixing the Age of an Upheaval.—In geological inquiries concerning time, the answer is always expressed in terms of the relative antiquity of stratified rocks; and a convulsion is fixed in geological time when it can be shown to have happened after the deposition of one stratum, and before the deposition of another. If the strata which thus limit the period of the convulsion be consecutive terms of the series of deposits, the most precise result is obtained; but if these limiting strata be not consecutive, the age of the disturbance is known only within a given range.

An example of accurate determination of the geological era of a convulsion is afforded in the North of England, where the newest of the coal strata are found to be dislocated under the oldest red sandstones of the Permian system.

Instances of less precise determinations are common enough: for example, in the Mendip hills the dislocated mountain limestone is covered by undisturbed oolite; and, as far as this observation goes, the convulsion may have happened during any part of the long period occupied in producing the coal, red marl, and lias strata. In this case, however, by tracing the line of the dislocation to other localities, other strata are found to be so related to the limestone as to fix the geological date of its disturbance within narrower limits.

If the dislocated strata be not actually seen covered by others which are undisturbed, another set of data must be employed. It may happen that around the disturbed rocks some newer stratum spreads in such a manner as to give sufficient reason to conclude that it was deposited since the period of the convulsion. This is, in most parts, all that can be observed with respect to the red marl around the igneous rocks of Charnwood Forest, and there would be satisfactory evidence that the slaty rocks of that district were upraised before the period of the New Red Sandstone; and, in fact, we have found instances where the red marl does really cover with level beds the broken edges of slate.

If no horizontal or undisturbed strata be visible in any part of the dislocated tract, either in superposition or in juxtaposition, the limit of least antiquity vanishes, and we are in danger of imagining too modern a date for the convulsion; if the newer members of the dislocated group of strata be concealed, there is danger of ascribing too high an antiquity to the convulsion.

Relation of Igneous Rocks to Convulsions.—The almost universal coincidence of convulsive dislocation of the strata with eruptions of plutonic rocks seems enough to prove their common dependence upon one pervading cause of internal movement. In the same manner as the modern earthquake precedes the eruption of lava, so the ancient convulsion or fault preceded the injection of plutonic rocks. Also precisely as in the present day the earthquake shakes countries far removed from volcanic centres, so in more ancient periods many tracts were dislocated, but the fissures thus formed were not filled with melted rocks, at least near the surface. As far as at first appears, the common dependence of the two orders of effect upon one cause is merely to the amount that the mechanical transference of melted rocks has been effected by the same internal pressure which dislocated the strata; whatever occasioned the pressure was also the cause of the fluidity of the rocks when the pressure was reduced or removed.

Various mechanical modes besides contraction may be conceived by which such pressure may have been occasioned, and various conditions assumed for the production of melted rocks, and these may be wholly distinct from one another; but the *exhibition* of these rocks along the lines of convulsion can only be ascribed to the same mechanical cause which produced the convulsion.

Fractures and Dislocations of Strata.

Faults.—Those dislocations known as "faults" which break the continuity of the beds along certain planes or fissures, and elevate or depress one side, often plainly declare themselves to be the result of single movements. Inspection of the phenomena in this country will leave no room for doubt that the dislocated strata were put into their present relations, not by a repetition of small and gradual movements, but by one movement, which may have been slow or rapid.

The extent of dislocation to which the name of fault accurately applies is extremely various, the difference of level thus occasioned being sometimes a few inches, in many cases 100 feet, in others more than 1000 yards. This marks out in very clear characters the degree of force exerted in each case. Those dislocations which make the greatest difference of level range through the greatest lengths of country. The ninety-fathom dyke—so named from the observed extent of its dislocation—ranges from the eastern sea across the whole breadth of Northumberland; and certain dislocations in Yorkshire have ranges of ten, twenty, and thirty miles in one nearly straight line.

Great Dislocations.—As far as we know, the greater portion of the convulsive movements of the earth's crust were accomplished by means of "faults." One of the most magnificent examples of dislocation in Europe is that grand break nearly along the line of the western border of Durham and Yorkshire, from near Brampton by Brough and Kirkby Stephen to near Kirkby Lonsdale, the effect of which is to throw down to the west the strata of the Carboniferous system more than 1000 yards through a length of seventy miles. An axis of slate rocks rises along the line of fracture, which is also partially marked by dykes of dolerite. On the west the beds dip at high angles to the west; on the east they decline gently to the east. No proper plane of fault is traceable in this case of enormous disruption, owing to the circumstances of the country. This line of disturbance is cut off to the north by the ninety-fathom dyke, and to the south by the Craven fault; and there is every probability that it is actually continued along the lines of these faults to a direction right-angled, or nearly so, to its own course.

Relation of Faults to Axes of Elevation.—Amongst these faults it is possible, perhaps, to distinguish two periods of disturbance, the older one marked by a direction nearly east and west, which is that of most of the metalliferous veins, the other by a direction from north to south, which is that of several whin dykes and some few lead veins. These different directions may have taken their rise from the two directions of the axes of convulsion which bound the district, and may mark successive periods of folding, and elevation of the ancient sea-bed still evident in axes of compression.

The limits of time by which the faults are defined are in many instances nearly coincident with the limits of uppermost Coal-measures and New Red Sandstone.

Some cases of disturbance are of a complicated nature. Such are the extraordinary retroflexures of the calcareous strata adjoining the Alps, the retroverted dips in the coal-fields of Somersetshire and Belgium, and the flanks of the Malvern hills. In some of these cases, as on the western side of the Malverns, and the western side of the Appalachian chain, we find the curvature often repeated in many synclinals and anticlinals; we see the slopes on each anticlinal steeper on the western side; and we remark that the anticlinals, taken successively from east to west, grow less and less steep, and more and more broad, as we proceed farther and farther from the mountain chain.

Dykes.

Dykes are concomitants of volcanic action, which owe their existence to the formation of fissures which extend from below upward, or in the planes of stratification. The fissure forms a vacuum, which draws the igneous rock up into its present position; and sometimes the fissure, by reducing the pressure, renders the igneous rock fluid. How far dykes may be produced out of the material of the strata

which they penetrate by reduced pressure in a plane of intrusion is still an open question. Dykes are formed during changes of level of land, and are exposed at the surface by denudation.

Ben Nevis.—The abundance and variety of felspar porphyry in great masses on the summit of Ben Nevis and in the valley of Glencoe are familiar to every traveller in the Highlands. The porphyry of Ben Nevis was shown by Von Oeynhausen and Von Dechen to have been erupted through the granitic basis of that mountain. The porphyries along the vertical precipices of Glencoe send veins through the subjacent granites, in number proportioned to the proximity of the situation to the great mass of porphyry. This rock varies through every stage, from claystone to felspar porphyry, the transition being sometimes gradual and sometimes sudden. Agglomerate composed of fragments of claystones and porphyries like those on Ben Nevis, and some in Cumberland, are often seen in Glencoe.

Ben Cruachan.—In the mountain of Cruachan, which overlooks Loch Awe, the hornblendic granite and schist rocks are traversed by a great variety of large felstone and porphyry dikes, and some changes of appearance happen to the mica schist. MacCulloch[1] describes the porphyry dykes as perpendicular, varying from 3 to 50 feet in breadth, traversing alike the schist and the granite veins, but not intermingling with either. Dykes of porphyry, of different kinds and colours, may run near or in contact with each other; but in all cases these and other dykes of basalt or porphyry are very distinct at the edges, though firmly united to the rock which encloses them. Fig. 68 shows veins of granite traversing the schist of Cruachan, themselves crossed by dykes of two kinds of porphyry.[2]

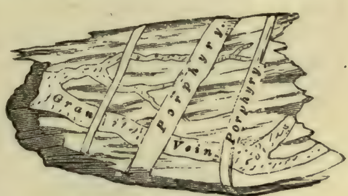


Fig. 68.

Cumbrian Mountains.—In the Cumbrian mountains felstone porphyries occur in many situations, and with a great diversity of character. Some have a basis of translucent grey or green felspar, and included crystals of glassy felspar and quartz; others are composed of a red, opaque, granular felspar basis, and red felspar and quartz crystals, as in rhyolites; the basis of others is compact felspar or hornstone, and some have a dark andesitic base, with small white opaque felspar crystals. Most of them, like the amygdaloids and dolerites of the same region, occur in overlying masses, as well as dykes. They seem to have a geographical dependence of a peculiar kind on the foci of granitic eruption. They are not abundant in or *very* near to the granite of Wastdale, Skiddaw, or Shap, but occur at small distances from each of those masses. The Valley of St. John shows pale red felspar porphyry overlying slate, well crystallised red porphyry in Armboth Fell, and various kinds of felspathic rocks under Helvellyn. Dykes of variable greenish porphyry divide the slates of

[1] Geol. Trans., iv.
[2] Ibid., iv., pl. vi.

High Pike, and a solitary red dyke ranges east and west of the granite of Shap Fells. No porphyry occurs very far from the granites.

North Wales.—In North Wales felspathic porphyries and dolerites are so connected by alternate bedding with the slates as to have been subjected to the same elevations and undulations of dip; and thus not only prove their high antiquity, but also suggest views as to the frequent recurrence of igneous action at the same points of the ancient bed of the sea during the Cambrian period. Dykes are even more abundant than interstratified igneous rock. For details reference may be made to Sir A. Ramsay's "North Wales."

Cornwall.—We may believe that all the complicated rocks, wholly or partially crystallised, composed of felspar, quartz, and mica, which are included between the slaty rocks of Cornwall, and which traverse them, are either the result of submarine eruptions during the formation of the Devonian slate; of the subsequent action of the heated granitic masses upon the killas; or are subsequent eruptions of melted rock into fissures caused by convulsion, or result from some gradual conversion and transfer of mineral ingredients. It is difficult to reason on dyke phenomena so remarkable as those of Cornwall without reference to other districts. The student may consult the writings of J. A. Phillips, F.R.S., on Cornwall, in the "Journal of the Geological Society," already quoted, for details of their distribution.

Fig. 69.—Caldron Snout, Teesdade. A waterfall in subprismatic basalt of the "whin sill."

Basalt of Teesdale.—The basaltic formation of Upper Teesdale in Yorkshire was described by Professor Sedgwick, and its continuation through Northumberland was traced by Mr. Hutton. The great mass of basalt called the "whin sill" forms a layer of irregular thickness, enclosed among strata of the Carboniferous limestone series, generally on the same horizon, so that in the valley of the Tyne

its place in the section is constant, and it occupies generally the same situation in Teesdale, though in Weardale another layer of basalt occurs. We cannot doubt that its thickness at different places was effected by their proximity to the eruptive channel. In the short space of six miles, from Caldron Snout to Hilton Beck, its thickness is diminished by 200 or 300 feet to 24 feet, and farther south it disappears totally. But to the northward the range is interruptedly continued to the sea-coast of Dunstanborough.

No dykes pass from this mass in Teesdale into the rocks above or below; so that a first view of the case suggests the idea that it was poured out as a mass of submarine lava upon the yet incomplete deposit of the Carboniferous limestone. Professor Sedgwick, however,[1] maintained that it was injected from below amongst these

Fig. 70.—High Force, Teesdale. A waterfall in columnar basalt of the "whin sill" over limestone.

strata, and that it penetrated between the planes of the strata by violently separating them.

The strata in contact are altered by the basalt in several ways, as may be seen about the High Force. The subjacent shales have a prismatic structure so as to be mistaken for basalt, are generally grey or whitened, and rendered brittle by condensation, but not much hardened. The sandstones are in several places highly hardened, rendered brittle and full of fissures, and much whitened. The limestones below the shale are remarkable for having their top bed full of iron pyrites; those above the basalt but not in contact with it are frequently changed from a full blue, hard, rather crinoidal limestone, first into a pale blue, crystallised, soft marble; and finally

[1] Camb. Phil. Trans.

into a loose, granular, saccharoid rock, in which, nevertheless, some traces of organic remains, such as crinoidal column, remain. But the most remarkable effect is the generation of garnets in the contiguous shale under the basalt of Cronkley Scar; a case analogous to that described by Professor Henslow [1] in connection with the dykes of Plas Newydd.

The igneous rocks themselves are chiefly a fine-grained dark basalt, changing to a coarse-grained dolerite. Contemporaneous veins of very beautiful hypersthenic rock pass through the basalt in several points, and it is traversed by a few productive lead veins.

The connection of several extensive basaltic dykes with this great "whin sill" has been rather assumed than proved.

These dykes pass in directions to the east-north-east, east-south-east, and nearly east, and they take straight lines through all sorts of rocks. Their respective breadths, and the quality of the rock in each, are nearly uniform, though in these particulars they differ from one another.

Cockfield and Armathwaite Dyke.—The Cleveland or Cockfield dyke, in particular, ranges for seventy miles through the coal series, where it chars the coal, hardens the sandstones, and whitens the shales; the lias shales and sandstones of the oolite series are affected like the coal system below. Generally it is a nearly vertical dyke, but at Cockfield Fell is subject to oblique expansions of a singular kind. The dyke which passes east-north-east is remarkable for having a small vein of lead ore running by the south-east side of it, and for converting the shales through which it passes to the state of a soft, whitish shale, called "pencil-bed," like those in connection with the whin sill. It does not cut through the magnesian limestone.

This dyke, well described by Sedgwick, appears first about six miles south of Whitby, near Maybecks on Swerton High Moor. It extends W.N.W. by Egton Bridge, Amthorpe, Ryehill, and Ayton, to Munthorpe in the Vale of Cleveland. Its thickness increases along this line from 18 feet at Maybecks to 80 feet at Great Ayton, though the top of the dyke is only 20 feet thick at the latter place. In this distance of 20 miles the dyke is intrusive in Oolite and Lias, and forms a conspicuous feature on the moors east of Selhone. West of Nunthorpe it extends by Stainton and Preston, where it makes an abrupt bend. It reappears after an interval at the village of Bolam, and extends to Cockfield Fell. Near Bolam it is 200 to 300 yards wide; near Cockfield it terminates abruptly beneath the stratified rocks, and in this district it is quite vertical. The altered shales and sandstones in contact extend to a distance of 20 to 30 yards. Though absent from the surface for some distance, it is proved to extend over Woodland Fell to about one mile east of Middleton.

The dyke of the Eden valley, which extends from Renwick to Armathwaite, is a portion of the same intrusive mass, and nine ex-

[1] Geol. Trans.

posures connect it with Cockfield. This outburst is of post-jurassic age; Mr. Teall suggests that it may perhaps be Miocene. In chemical composition it closely resembles the augite-andesites of the Continent.[1]

The Hetts Dyke.—According to Professor Sedgwick this dyke ranges from the escarpment of magnesian limestone at Quarrington Hill, east of Durham, in a W.S.W. direction by Tarsdale, Hetts, Whitworth, through the collieries of Bitchburn and Hargill Hill, and up the Bedburn Beck valley to Egglestone Moor. The thickness increases westward from 6½ feet to 15 feet. At Hetts the dyke leads to the north at a high angle. It bakes and indurates the rocks with which it is in contact. It differs from the Cleveland dyke in wanting porphyritic crystals of felspar. Two miles to the north of the Hetts dyke is another dyke of the same composition; and there is a horizontal sheet between the two at sixty fathoms below the surface. Sedgwick regarded this dyke as palæozoic.

The High-Green Dyke.—The High-Green dyke, which crosses the Parret, runs west to east, and is 50 feet thick along the stream. Its central part is coarsely crystalline. On the north wall it is cellular.

The Acklington Dyke.—This dyke stretches from the coast at Bondicar near Acklington, where it is 30 feet thick, through the Carboniferous rocks and Cheviot porphyrites, and runs for many miles across the South of Scotland. It is well seen near Newton and Chennel, about eighteen miles west of Acklington.

The Hebburn Dyke, according to Professor Lebour, emerges from beneath the magnesian limestone near Cleadon, passing W.N.W. by Hedworth and Hebburn to the Tyne. The Coley Hill dyke, west of Newcastle, is sometimes supposed to continue the line. This dyke is 44 to 50 feet thick. It cuts no formation newer than the Coal-measures.

The Tynemouth Dyke is seen at Tynemouth on the shore in contact with the Coal-measures. It is 10 feet wide, and divided into two parts by a quartz vein 6 inches thick. Mr. Teall regards the Coley Hill dyke as a part of the Tynemouth dyke.

Brunton Dyke.—Professor Lebour traces this dyke[2] from West Allendale over the South Tyne to west of Haydon Bridge; over the North Tyne, near Wall, to St. Oswald's chapel, near Brunton; and it is last seen in the Bingfield Burn; so that its main direction is from N.E to S.W.

The Seaton and Hartley Dykes.—Several dykes run parallel to each other from N.W. to S.E., and are exposed on the shore between Seaton and Hartley. The dyke near Seaton, according to Mr. Teall, is 10 feet thick at the bottom of the quarry, 5 feet thick at the top. Another of the dykes is occupied by a rubbly mass in the centre.

The Morpeth Dyke is only seen crossing the Wasbeck, near Morpeth.

These are a few examples of dykes discussed by Mr. Teall, but they indicate some of the general features of such phenomena.

[1] Teall, Q. J. G. S., vol. xl. [2] "Geology of Northumberland."

Breaks in Succession of the British Strata.

There are two kinds of breaks in succession: first, the physical interruption in stratification, which is marked by unconformity; secondly, the palæontological break, which consists in a change in fossils without any necessary variation in the rock sequence. The latter condition can only claim to be a break in succession on the hypothesis that the change in life has been brought about by upheaval in some adjacent sea, which has caused the life to migrate away from the upheaved region, and thus has disturbed the succession of life, in an adjacent area which we may be examining, by causing an immigration which has changed its fauna.

Breaks in the Primary Rocks.—The nature of the break which divides the Harlech and Bangor groups of Lower Cambrian rocks from the unfossiliferous Pre-Cambrian is essentially a palæontological break due to the absence of fossils from the lower rocks, though the older beds are more highly volcanic. The fauna of these Lower Cambrian rocks includes 18 genera and 32 species, of which one-third pass into the Menevian. The Menevian beds again are defined in the St. David's area by a palæontological break. The fauna comprises 24 genera and 52 species, of which 19 pass into the Lower Lingula flags. The Lower Lingula flags is a palæontological group with 17 genera and 36 species, chiefly Crustacea, of which 2 pass into the Middle Lingula flags and 8 into the Upper Lingula flags. The Upper Lingula flags contain 16 genera and 41 species, of which 10 pass into the Lower Tremadoc and 7 into the Upper Tremadoc. Still there is no visible unconformity in the series, and therefore to the physical geologist they are essentially one group, which suggests many changes in the relations of land and water in adjacent areas, but shows that no new axis of upheaval was developed in the British region.

The Arenig rocks rest upon the Tremadoc. The deposit contains 96 species. Forty Graptolites here make their appearance for the first time; and of the 31 Crustacea only 6 live on from the Tremadoc, and but 3 pass up to the Llandeilo. Of the 149 species in the bed all but 38 are peculiar to it.

The Llandeilo beds contain 80 genera and 175 species; and 38 genera and 73 species pass up from them to the Bala beds. The fauna of the Bala group admits of subdivision into three. The Middle Bala contains 610 species, of which only 102 pass up to the Lower Llandovery. The Lower Llandovery beds, though easily distinguished from the underlying beds by their sandy character, show no unconformity in Central Wales, but near Llandovery, Sir Andrew Ramsay and Mr. Aveline recognise a slight unconformity at Noeth-Grug. These beds contain 204 species, of which 104 pass up.

Between the Lower and Upper Llandovery there is everywhere a perfect unconformity; and Sir A. Ramsay remarks that the newer beds rest on the denuded edges of the Lower Llandovery, sometimes on the Caradoc sandstone of the Bala series, and at Builth

and the Longmynd, on contorted and denuded Llandeilo and Cambrian rocks. The Upper Llandovery contains 91 genera and 261 species, of which 59 genera and 126 species pass up to the Wenlock. There is no clear and satisfactory unconformity of a visible kind here, though the Upper beds of the Llandovery series are sandstones and conglomerates indicative of shallower water conditions than those of the typical succeeding Wenlock beds. The Wenlock contains 536 species of fossils, of which 126 pass into the Lower Ludlow. The Ludlow fauna includes 137 genera and 392 species, and the beds have 129 species in common.

There is a complete break in life between the Silurian and overlying Devonian series, but there is no sign of unconformity or a break of any kind between the Ludlow rocks and the Old Red Sandstone. Yet only 20 species pass up into the Devonian, which is about one-thirteenth of the species in the Upper Ludlow rocks, and less than one-third of the fauna of the passage-beds. The Devonian rocks contain 195 genera and 544 species, of which 32 genera and 51 species pass up to the Carboniferous; but Sir Andrew Ramsay observes that round the Forest of Dean and the South Wales coal-field there is no sign of unconformity between the Old Red Sandstone and the Carboniferous series. Yet, although conformable to the strata above and below, the Old Red Sandstone includes distinct unconformities in Scotland.

The Carboniferous series is generally conformable from top to bottom, but the beds exhibit many oscillations of level. In the Forest of Dean, the Millstone Grit rests unconformably on the mountain limestone, but there is nowhere a gap that would correspond to the change in life. The fauna comprises no less than 515 genera and 2409 species, of which only 51 species are derived from the Devonian, and only 8 species pass up into the Permian.

The Permian rocks show a marked unconformity resting on all the Primary strata. The fauna is poor, and, so far as Brachiopoda are concerned, is largely composed of species which live on from the Carboniferous. Thus there appears to be a more marked physical distinction between these strata than suggests itself on an actual comparison of Permian with Carboniferous fossils; and we find that the physical break is not coupled with a palæontological break.

Breaks in the Secondary Strata.—We now come to the great stratigraphical break which marks the commencement of the New Red Sandstone; and nowhere is there an actual passage downwards into the Permian. The Triassic rocks are very imperfectly represented in this country, and the series includes some unconformities, since near Ormskirk the New Red Marl lies unconformably on the New Red Sandstone. Only one Trias species appears to range into the Lias. There is no appearance of unconformity between the New Red Marl and the Rhætic beds, although the latter are a marine series.

The Lias is so closely connected with the Rhætic beds, that the separation between them has only been made during the last twenty years, and there is no visible unconformity in the Lias; but the per-

centages of species which pass between the divisions of the Lias are remarkable. Thus about one-third of the species pass from the top zone of the Lower Lias into the Middle Lias; and from the top of the Middle Lias only about 5 per cent. pass into the Upper Lias; while from the Upper Lias 27 per cent. pass into the Upper Lias sands, and 21 per cent. into the Inferior Oolite. One hundred species are recorded from the Rhætic beds, 281 genera and 1830 species occur in the Lias, of which 1080 are in the Lower Lias, 562 in the Middle Lias, and 418 in the Upper Lias. Forty-five species survive to the Inferior Oolite, and 11 to the Great Oolite; about half in both cases being bivalves.

There is no complete physical break between the Inferior Oolite and the Lias, though the mineral character of the bed alters, and between Yorkshire and Gloucestershire this might be considered to amount to an unconformity. The Inferior Oolite contains 1000 species, of which 65 extend into the Fuller's Earth, and 175 into the Great Oolite. The Fuller's Earth thins out entirely to the N.E. of Cheltenham. It is only known to contain 110 species, of which 65 are common to the Inferior Oolite, and the same number range up to the Great Oolite.

The Great Oolite contains 820 species, of which 84 range to the Forest Marble and 120 to the Cornbrash. The Forest Marble contains 136 species, of which 48 range up to the Cornbrash. Between Yorkshire and Dorsetshire all these lower oolites may be regarded as unconformable to each other, though no actual unconformity is seen.

The Cornbrash may be regarded as forming a break with the underlying strata, since it is the only deposit of the Lower Oolites which ranges through England from Dorsetshire to Yorkshire. It contains 244 species, of which 56 range up into the Kellaway Rock, and 48 range down to the Forest Marble. The Kellaway Rock has 168 species, of which 60 pass into the Oxford Clay. The Oxford Clay contains 73 genera and 194 species, of which 48 pass up into the Coralline Oolite and 25 into the Kimmeridge clay. Still there is no visible physical break in the succession in the British area. The Corallian fauna, which abounds in lamellibranchs, gasteropods, echinoderms, and ammonites, comprises 116 genera and 334 species, of which only 14 are corals. The Kimmeridge Clay only receives 33 species from the Coralline Oolite, and of the 263 species found in the bed, only 22 survive into the Portland Oolite. The Portland Oolite, greatly limited in its area, has a fauna of 128 species, of which none survive to newer rocks.

The Purbeck beds pass so insensibly into the underlying Portland, that the difference is only to be detected by the fossils; but since the Portland beds are marine, and the Purbeck largely fresh water, an unconformity must exist. Similarly an unconformity must be inferred for the overlying Wealden beds, the distribution of which is different from the Purbeck beds; but there is no trace of an unconformity between the Wealden and the Lower Greensand till we pass west and

find the Greensand of Dorset and Devonshire resting unconformably on the oolites and older rocks.

About 18 per cent. of the Lower Greensand species pass up into the Gault, but 40 per cent. of the Gault species pass into the Upper Greensand. The Upper Greensand has 20 per cent. passing into the Chalk Marl. The Chalk Marl has 59 per cent. passing into the Lower Chalk, and the Lower Chalk has 31 per cent. passing into the Upper Chalk. It is doubtful if any species really survive from the Chalk into the Tertiaries.

Breaks in the Tertiary Strata.—In this country the physical break between the Secondary and Tertiary strata is of the largest kind, and presumably consisted in an upheaval of the sea-bed, so that what had previously been an area covered with organic deposits free from sediments was succeeded, after a certain amount of denudation, by sediments derived from crystalline rocks. But though the Tertiary rocks repeat in their subdivisions differences in life as remarkable as those which have been mentioned already in the successive beds of the Primary and Secondary series, and further contain conglomerates, fresh-water deposits, and several zones rich in land vegetation, indicating oscillations of level, there are no visible physical breaks till after the close of the Hempstead beds, with which the Lower Tertiaries terminate. Whether any newer deposits were ever accumulated in the British area it is now impossible to determine, but the land may well have been upheaved and dry during the Middle Tertiary or Miocene times. It is certain that an immense physical break is indicated by the interval between the Lower Tertiaries and the Upper Tertiary Crags, which exhibit an absolute unconformity with the strata on which they rest. The Red Crag rests unconformably on the Coralline Crag, and the Boulder Clay rests unconformably on the Red Crag.

Thus the number of physical breaks in the British area is inadequate to account for the breaks in the succession of life. There is no evidence of denudation which would warrant an explanation of the breaks in life by assuming missing deposits; and we are hence compelled to attribute the seeming breaks, in the main, to disturbances in the relations of land and water in adjacent seas which affected the distribution of life in the region which is now Britain, and at the same time varied the mineral character of the sediments in which the fossils became preserved.

Table of Disturbance in the British Area.

The following table prepared by Prof. John Phillips shows the geological periods of many remarkable convulsions in Great Britain, and the places where some of the most considerable effects are manifested :—

No. Geological Period of the Convulsions.	Effects Noted.	Localities of some of the Phenomena.
During the deposition of the Harlech and Bangor grits .	Production of Conglomerates . . .	Derwent Water Cumberland, North Wales.
	Porphyry and dolerite and Trappean Conglomerates . .	Grasmere in Westmoreland, Radnorshire, Merioneth, &c.
I.—After the Silurian strata and before the Carboniferous system . . .	Disturbed position of Primary rocks ; volcanic outbursts .	The Grampians, Lammermuirs, Cumbrian Mountains, North Wales.
	Production of Old Red Conglomerates .	The Highland Border, Cumbria, &c.
During the Carboniferous period .	Marine bed among estuary deposits .	Yorkshire.
II.—Before the adjacent rocks of the Permian system taken generally . .	Numerous dislocations, fissures of dykes and veins, anticlinal axes, &c. . . .	In all Coal Districts of this era, both in Europe and America. Charnwood, Crossfell fault.
During the Permian period . . .	Production of Conglomerates . . .	North of England, north of Germany.
III.—After the earlier Permian period ? .	Veins of lead, &c., Great or 90-fathom dyke .	Yorkshire, Pontefract, Mendip hills, Tynemouth castle, border of Cumbrian group (Kirkby Stephen).
After the later Permian period . .	Production of New Red Conglomerates	North of England.
During the Oolitic period ? . .	Unconformity. Kelloway rocks in contact with the Lower Oolite group, excluding the upper portion .	Cave, Yorkshire.
IV.—After the Oolitic period . . .	Unconformity of strata between Oolitic and Chalk systems .	Yorkshire wolds, Dorsetshire cliffs.
	Estuary deposits. Pebble beds of Lower Greensand . .	Weald of Kent and Sussex, Isle of Wight, &c.
During the Chalk period ? . .	?	
After the Chalk period . . .	Pebble beds, wasted surface of chalk .	Hertfordshire, Vale of Thames.
V.—After the Eocene deposits . .	Vertical strata . .	Isle of Wight, Isle of Purbeck.
	Marine deposits between lacustrine beds	Isle of Wight.
	The crag . . .	Essex and Norfolk.

The Roman numerals are applied in the above list to all periods where considerable movements are traced in direct effects of dislocation and conformity.

The next table presents the results of a more extended survey of direct convulsive effects on the continent and islands of Europe, as they appeared to E. de Beaumont on the first proposal of his ingenious views of subterranean movement :—

Table of Disturbance in the European Area.

No.	Geological Period of the Convulsions.	Effects Noted.	Localities of some of the Phenomena.
I.	(1 and 2, E. de B.)—Before the Old Red Sandstone .	Anticlinal axes and great faults of the Slate system . .	The Hunsdrück and Taunus.
II.	(3, 4, 5, E. de B.)—*a.* Before the Rothetodteliegende .	Immense disruptions and faults of the Coal system . . .	Calvados, south-west border of the Vosges.
	b. Before the Zechstein . . .	Immense dislocations and faults of Coal strata . . .	Westphalia, Belgium.
	c. Before the New Red Sandstone .	Immense dislocations and faults . .	Vosges, and Black Forest.
III.	(6, E. de B.)—Before the Lias .	Mountain ridges of Zechstein, &c. .	Thuringerwald and Böhmerwald.
IV.	(7, E. de B.)—Before the Lower Greensand . .	Abrupt and distorted strata of Oolitic system . . .	Mont Pilat, Cevennes (perhaps the Erzgebirge).
V.	(8, E. de B.)—Before the uppermost Chalk beds . .	Abrupt elevations of Greensand and Lower Chalk . .	Mont Viso, Devolny.
VI.	(9, E. de B.)—Before all the Tertiary rocks . .	Elevations of Chalk and Greensand .	Pyrenees, Northern Apennines, the Morea.
VII.	(10, E. de B.)—Before the Nagelflue . . .	Detached ridges . .	Corsica, Sardinia, Auvergne.
VIII.	(11, E. de B.)—Before some Glacial beds . .	Newest Tertiaries uplifted . . .	The range of the Western Alps, Diablerets, Mont Blanc.
IX.	(12, E. de B.)—During the formation of other Pre-Glacial beds .	Some Diluvial beds covulsed . . .	The range of the Eastern Alps from the Valais to Austria.

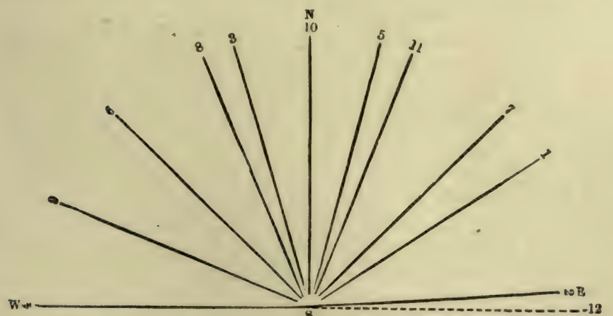


Fig. 71.—E. de Beaumont's System of Elevations.

1. Snowdon.
2. Ballons, Bocage.
3. Crossfell.
4. Pays Bas.
5. Rhine.
6. S.W. of Brittany.
7. M. Pilas, &c.
8. M. Viso.
9. Pyrenæo-Apennine.
10. Corsica.
11. W. Alps.
12. Alps.

Elie de Beaumont's Generalisations.—The following is De Beaumont's view of his first five systems, including applications in Great Britain for comparison with the details of Professor Phillips' groups I. and II. :—

No.	Geological Period of the Convulsions.	Effects Noted.	Localities of some of the Phenomena.
I.	1. During the deposition of the lower Palæozoic strata, anterior to upper Silurians .	Elevation of mountain chains . . .	Snowdon, Anglesea.
	2. Posterior to the upper Silurians, anterior to Old Red Sandstone .	Great faults, and anticlinals . .	Grampians, Lammermuirs, Cumbrians.
II.	3. After the Coal strata and before Rothetodtelie-gende . .	Immense disruptions and faults of the coal.	From Derbyshire to Northumberland along the Western border of Yorkshire, Malvern.
	4 After the Coal strata, and before the Zechstein .	Ditto	Westphalia, Belgium, Mendip, South Wales.
	5. After the Coal strata, and before the Bünter Sandstein . . .	Great disruptions .	Vosges and Black Forest, from Basle to Mayence. Faults in magnesian limestone of northern counties.

Elie de Beaumont's Hypothesis.—It has long been known in mining countries that the faults take parallel directions, and sometimes two or more systems of dislocations, crossing in certain angles, were found to be of different antiquity. That dislocations were in some respects to be compared to the effects of earthquakes was also well understood, but no one before De Beaumont appears to have carried his notions of the coincidence between the lines of convulsion and the direction of the great physical features of the globe so far as to venture on the construction of a general system. This excellent geologist believed that there is a constant dependence between the direction of the dislocation and the geological epoch of its occurrence, such that all the dislocations of the same age are parallel to one and the same great circle of the sphere ; and that, *in most instances*, dislocations of different ages are parallel to different great circles, which intersect one another at assignable angles owing to the shrinkage and parallel crumpling of the earth's crust. This general hypothesis is not to be tested by single or small dislocations. It must be examined on a great scale, by means of very exact and numerous data. The facts known are not clear and numerous enough to demonstrate this hypothesis ; and on the other hand there are not facts to warrant the unconditional rejection of it. It is certainly founded on important data, and in several instances agrees well with observation. The principal difficulty of applying satisfactory tests to its application, arises from the uncertainty of the exact date of many of the most characteristic convulsions. We cannot positively tell

whether the dislocations of the Grampians and Lammermuirs, which take parallel courses, were geologically synchronous or not, because the beds dislocated are not the same. Even in the case of the great faults which followed upon the Carboniferous system, the limits of the geological epochs of their occurrence are often too vague for the application of such a theory. Rothetodteliegende and magnesian limestone cover the coal of the North of England unconformably, and thus define the date of the convulsions. But in the South of England these rocks are of rarer and less regular occurrence, and often entirely wanting, and then the New Red Sandstone above the coal gives only a vague approximation to geological time.

Three great Groups of Earth-Movement in Britain.—The subjoined diagram (fig. 72) is intended to show the directions of three great movements of strata in Britain which appear to be grouped in traceable systems.

The earliest is that N.E. and S.W. system which includes Snowdonia and a large tract about it. By this the Cambrian strata, as understood by Sedgwick (including the Lower Silurian of Murchison), have been much disturbed in North Wales, so that unconformity appears between them and the lower part of the Upper Silurians.

Another great system of movement is typified in the North of England by the great faults and anticlinals of the Pennine chain, varying from N.N.W. to S.S.E.

Nearly parallel to this are the dales of the Nith and the Annan, the Dee and the Clwydd. These dislocations precede the whole mesozoic system.

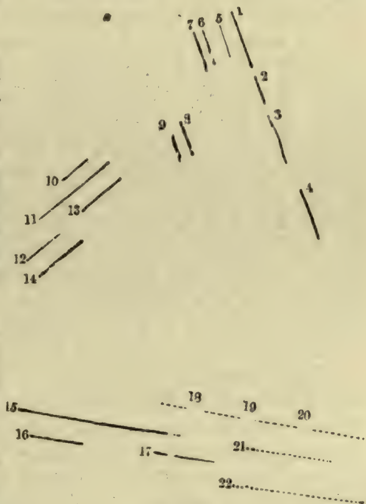


Fig. 72.

Three Systems of Subterranean Movement in Britain.

1. Clyde.	8. Dee.	15. S. Wales.
2. Eden.	9. Clwydd	16. N. Devon.
3. Ribble.	10. Menai.	17. Mendip.
4. Derbyshire.	11. Snowdon.	18. Wilts.
5. Annan.	12. Dolgelly.	19. Highclere.
6. Nith.	13. Bala.	20. Surrey.
7. Ken.	14. Dyfi.	21. Sussex.
	22. Isle of Wight.	

A third series of parallel or nearly parallel movements affects the south of Ireland, South Wales, and the South of England. In South Wales, the Mendip Hills, and North Devon, it disturbs all the strata earlier than Permian; and in the Isles of Purbeck and Wight, and the Weald, it disturbs all the Eocene strata. This appears a case of nearly the same direction, and nearly the same kind of movement (anticlinals and synclinals), affecting a given district in different geological times. The earlier movement was continued both eastward and westward, so as to embrace a length of fully 700 miles of the earth's surface—from Bantry Bay to Elberfeld. The later

movement affected a large breadth of country—from the Isle of Wight to beyond the Thames valley, and is parallel to the upheaval of the Alps, and the axis of elevation of central Europe of which it is a consequence.

Elevation the Consequence of Convulsion.—That the effect of convulsions has been, generally, to raise the convulsed area, will appear evident by considering what is the focus of the disturbance and the direction of its energy. The mountain chains and groups are most certainly the foci of the disturbing forces; for as we pass towards them, from all sides the number and intensity of the dislocations continually increase, and the inclination and contortion of the strata grow more and more violent. The direction of the disturbing force is clearly seen to be horizontal, while its effects are vertical or nearly so, and thrust the folded masses outwards from the central regions of the earth. It is like an expansive force, which employed its principal efforts along certain lines and about certain centres, breaking and bending the strata in the highest degree, but also lifting them up on all sides around. Although the Mediterranean lies between the Atlas chain and the Alps, the elevation of mountain chains and groups was generally unaccompanied by any neighbouring violent depressions, because the upheaval is only a part of a predominant upward bending of the earthy crust. The inclination of the strata from mountain chains for the most part gradually subsides to a gentle slope, and finally vanishes in nearly horizontal planes. In the mountain chain itself various and suddenly reversed dips may be met with corresponding to the violence of the disruption, but by careful study the general tendency of the convulsion may be clearly deciphered.

The same data will not, however, by any means give us right to conclude that the mountains so brought into existence were raised above the sea, because, though we may know the absolute height of the vertical movement, this will avail us nothing in our ignorance of the original depth of the water. We must see whether mountains bear on any part of their surface traces of those later marine deposits which spread around their bases; if they do, we may be sure they were not elevated above the sea till after the date of these strata; and the Alps, for instance, bear upon their crests portions of oolitic, cretaceous, and tertiary strata, and are thus proved to be of more recent elevation than the geological age of the strata uplifted. If the newer marine strata around their bases have been deposited horizontally against the slopes of the mountains, we are entitled to believe that the mountains had been previously reared above the sea. This conclusion, however, it must be always borne in mind, does not inform us correctly concerning the height they were reared above the sea, but leaves us to infer that they have since partaken of another movement by which the newer strata have been placed at their present elevation.

Collateral Effects of Upheaval and Depression.

Relation of Lines of Upheaval to Magnetic Intensity.—M. Necker, in a communication to the *Société d'Histoire Naturelle de Genève*, traced a very unexpected coincidence over large portions of the northern hemisphere, of the direction of the strata, and the curves of equal magnetic intensity, as drawn by General Sabine. One of these curves, that of 297 seconds, traverses Scotland in a direction north-east and south-west, which is exactly that of the strata. It keeps the same direction by Christiania in Norway, where the strata trends north-east and south-west, and passes through Sweden where the same direction of strata predominates. On arriving at the Gulf of Bothnia the magnetic curve turns north-west and south-east, which, according to Strangways, is the direction of the southern border of the Swedish and Russian granite.

The curve of 308 seconds enters Europe by Lisbon, and passes south-west and north-east through the Spanish peninsula, which is nearly the line of most of the long sierras between the great rivers; it passes by the Cevennes, and goes parallel to the Alps in their north-east course to the Tyrol, but there turns south-east, as do also the lines of stratification through Carniola, Istria, Croatia, Dalmatia, and the Morea. Parallel to these are the Carpathian mountains. The same correspondence between the magnetic curve and the lines of folding of strata is traced through the Crimea and along the Caucasus.

In North America the magnetic curve and the stratification range north-east and south-west along the whole eastern coast; in the Rocky Mountains both extend from north north-west to south south-east; in Mexico the magnetic curve takes the parallel of the Cordillera of Anahuac north-west and south-east, and ranges along the south coast of New Spain. Farther to the south the curves resume their course north-east and south-west, which, according to Humboldt, is the direction of the strata in Venezuela, and between the Orinoco and the Amazons. The chain of the Himalaya, which in Nepaul bears north-west and south-east, and turns north-east at the north-east extremity of Bengal, is parallel to the curve of 297 seconds which was first noticed. Whether the thermal conductivity of strata governs their magnetic intensity, or whether alternation of mineral character governs inductive electrical action of strata on each other, or whether the compressions and tensions of contortion have modified magnetic characters of strata, are problems not undeserving the attention of the physical geologist, but too special for examination here.

Possible Changes in Ocean Level from Depression of Land.—The variability of the ocean level in consequence of displacements of the solid land may be stated under three hypothesis:—

First, We may suppose no vacuum to exist below the crust of the earth, nor any receptacle into which the solid land could sink, but that a sinking in one place should be compensated by a rising in another, so that the cubic dimensions of the globe remain unchanged.

Moreover, to put an extreme case, it may be a condition that the land shall sink so that water shall cover the whole surface. In this case the level of the ocean would rise, that is, the mean radius of its curved surface would be lengthened, by a quantity depending on the mass of the solid land submerged, and on the relative area of land and water. This relation of area is more than 3 water to 1 land. The cubic content of the solid land may be thus estimated. In England, Wales, and Scotland, the average height of those conspicuous mountain masses which appear to give shape to the whole country is about 30,000 feet; and if we consider this as the apex of a cone whose base is the whole area, we shall have the mean height of the land above the sea $= \frac{3000}{3}$ feet. The mountain masses, however, do not really affect, by their special elevation, more than a fraction of the area of the British Isles; the far greater part of the land depends on heights not exceeding 1000 feet. If the mountain tracts be called half of the area, and the hilly and more depressed parts half, we shall find the mean height of the whole mass of land $\left(\frac{3000 + 1000}{3 + 2}\right) = 666$ feet. But on account of the valleys which divide the principal masses, we may reduce this to say 500 feet.

This principle applied to the continents of Asia and America would give in round numbers about 2000 feet mean altitude of land; and as the area of the expanded ocean would be four times as great as the land is now, the total mean elevation of the water, by the submersion of the whole mass of land, would be about 500 feet; a quantity too small to be of use in explaining any but the lesser order of geological phenomena, and which may be considered as the extreme limit of oceanic rise under these conditions.

Secondly, We may suppose the existence of cavities into which the solid land might sink, so that there may be no elevation in another place corresponding to the given depression. To put this also to extreme, we may imagine the very improbable case that a mass of solid materials, equal in bulk to all the solid land above the water, should sink into a cavity, and that the surface of the submerged land should be level. The level of the ocean would be nearly unaltered, except in a small degree, by reason of its shallow expansion over the area of the land. We might go on to suppose even the enormously improbable case of cavities existing so large as to admit twice the whole solid mass of the continents, and that these should sink with an equal bulk of materials into these cavities. Even in this case the ocean level would only be lowered 500 feet.

Thirdly, If we suppose contemporaneous or successive elevations and depressions, however extensive, the ocean level would oscillate about a constant line.

It is evident, therefore, that by no stretch of conjecture, that is not absolutely absurd, can we torture the known laws of terrestrial arrangements into agreement with the hypothesis of any but small changes of level of the ocean; a conclusion which enables us to

argue upon that level as a general standard to which we may refer all the effects of internal movements, in whatever period, and by whatever forces produced. It fixes no limits to the effects of the temporary violence induced in the ocean by such movements, because these effects would be in proportion to the impulse with which they originate.

Mountain Ranges.

Study of Mountains.—Long chains and insulated groups of mountains form, so to speak, the skeleton of the earth, and are the fundamental features of its topography; their insulated groups characterise kingdoms, their long connected chains divide the races of mankind, and define the geographical limits of the distribution of land animals. The principal ranges of mountains everywhere contain in their axes similar rocks, which are often the lowest, and among the oldest, with which we are acquainted. By lateral contraction they have been lifted to their present heights, so as to break through and rise by denudation from beneath the strata which were superimposed upon them in succession.

These mountain-forming materials comprise gneiss, mica schist, slate, and many associated rocks, resting upon and often pierced by granite and similar crytallised compounds.

Though we speak of long-continued chains and belts of mountains, it is certain that to be crossed in groups is the real character of mountain association, and that the chains and belts are nothing but approximated groups. A geological map is in this respect a most valuable instructor; from it we see that, instead of the plains being commonly insulated among the mountains, the newer strata spread wide, and round the bases of the mountains, as the ocean encircles islands and continents. We may observe that the most insulated and many of the loftiest eminences on the surface of the earth are volcanic summits. The most connected ranges of uniformly high ground are formed by limestones.

Elie de Beaumont supposed that all ranges of mountains which were uplifted at the same period are parallel to the same great circle on the sphere. Parallel ranges are an effect that lateral pressure would produce.

If a great circle be conceived to pass round the earth through Natches and the mouth of the Persian Gulf, and the directions of mountain chains be compared with it, it will appear that the Pyrenees, part of the Apennines, the Dalmatian and Croatian ranges, and part of the Carpathians, are parallel to it. In accordance with the researches of some geologists, M. de Beaumont supposed that all these mountain chains were thrown up at the same geological epoch.

Another circle may be traced on the sphere parallel to the Alps, from the Valais to Styria, and to this system we may refer the Atlas, the Caucasus, the Balkan, the Himalaya, &c.; and, according to the hypothesis of M. de Beaumont, these must have been all raised since

the deposit of the tertiary strata. This is the effect that lateral contraction should produce.

Lateral Displacement as the Sole Cause of the Formation of Mountain Chains.—Professor Heim states that a contraction of only $\frac{1}{100}$th of the earth's circumference would be sufficient to fold all the rocks in the mountain masses which would be crossed by a meridian traversing the Alps. Even the central crystalline mass of the Alps has undergone enormous lateral compression, and is now reduced by crumpling to half the width to which it once extended. These phenomena of compression have been especially studied in the mountain mass of the Tœdi, which is an enormous block of jurassic limestone in the Grisons, separated by prodigious denudation from the surrounding masses. In this neighbourhood many of the folds are highly complicated. One great contortion, bent over towards the north, piles upon the Nummulitic rocks, the Jurassic rocks, the Verrucano, which is partly of Carboniferous age, the porphyry of Windgælle, and gneiss. In the direction of the Windgælle mountains, this fold breaks up into a number of minor folds; and at the southern border of the central mass, the chain of the Piz Tumbrif is formed from a fold which has itself been folded, by which the middle zone forms greatly compressed synclinals.

Mountains of the European Basin.

The Ural Chain forms the western limit of the European basin. It is a water-parting, which must have come into existence as a long island, whose eastern slope the older geographers separated from the western slope, as though they were distinct parts of the world. This chain is one of the older features in geological history, though certainly newer than the western contour of the continent. Broken as that contour is by the inlets of the North Sea and the Bay of Biscay and the isolation of Britain, it needs but the help of a geological map of Europe, and a map of the hundred-fathom soundings, to recognise that the Scandinavian chain, now ending with the peninsula, strikes away south-west to Shetland, the western Highlands of Scotland, and north of Ireland, and is prolonged further south beneath the sea, so as to have outlined the eastern side of the great Atlantic Valley, or to have formed a ridge parallel to the Dolphin ridge, before the Atlantic was defined by land.

Old ridges, generally rising to the west of Britain, but sometimes elevated also to the east, come again and again under notice of the British physical geologist, as parent masses from which the sedimentary materials of primary and secondary rocks were derived, and varying elevation of which governed the succession of British strata.

But the European basin in its present form is essentially a product of forces which began to operate with the Tertiary period. This elevation runs eastward through Europe and Asia, and links the south of Europe with the north of Africa, in a way of which the Mediterranean, at first sight, gives no indication. Grand contractions of the

earth's crust, travelling from north to south, have crumpled up the rock masses into parallel ridges running east to west, the slopes of which form the great Eurasian and North African continent; for the north of Africa, like Europe, has its chief extension from east to west.

In endeavouring to understand the conformation of Europe, we may begin by noticing the east to west extension of the Cantabrian mountains and Pyrenees. Parallel to these, crossing the tableland of Castile, are the Guadarama mountains, mountains of Toledo, the Sierra Morena, the Sierra Nevada, divided from each other by valleys more or less deep; while farther south are the chains of the Little and Great Atlas, parted from the Sierra Nevada by a deeper valley which admits the ocean. Turning next to the east of Europe, we find in Asia Minor another tableland, comparable to Spain, bordered to the north by the Caucasus and traversed by parallel ranges, which run east and west.

We may then perhaps conceive how it has come about that the intermediate Mediterranean region acquired its peculiar contours, owing to downward or synclinal folding, which has not sunk mountains out of sight like those east and west, but has prevented them from being formed, by using up the materials of the earth's crust in the production of folds of a different order. Whoever will experiment on the contraction or crumpling of materials on spherical surfaces, will see that, with a predominant anticlinal elevation, an arrangement of primary folds at right angles to the compression is produced, but whenever a moderate synclinal depression is formed on the flank of the main axis of elevation, then lateral chains or spurs are formed, more or less at right angles to the main ridge, but under inverse conditions to those in which William Hopkins demonstrated the two orders of fractures dependent upon strain in an anticlinal elevation.

Between the Caucasus and the Pyrenees lie the whole system of mountain ranges of the south of Europe, which consists of main chains and spurs. The chain of the Cevennes runs north as though it were a spur dependent upon the Pyrenees; but the mountain axis of the Pyrenees, interrupted for a time by depression in the Gulf of Lions, becomes prolonged into the Mont des Maures in France, and is deflected northward parallel to the Cevennes, forming the Graian and Cottian Alps, before it resumes its main direction east, in the Pennine Alps, the Lepontine Alps, the Rhætic and Noric Alps, which strike away eastward to the Carpathians. Dependent upon this great range are parallel subordinate ranges; and spurs are given off to the south and north. It seems to be a characteristic of a spur that an intervening area of depression separates it more or less from the main chain upon which it depends; for we find not only the chain of Corsica and Sardinia running south from the Gulf of Genoa as a spur from the Atlas or the Alps, but the Apennines extending S.E. from the Alps as the axis of a peninsula which is a secondary consequence of the great Alpine elevation. Similarly the Julian and Dinaric Alps, like the northern spurs of the Balkans and the Siebenbürgen of eastern Transylvania, run south-east. If the southern

mountain spurs form peninsulas which point to the south, it is only because the depression of the basin between Asia Minor and Spain, is coupled with great uplifting of the complicated folded mass of the Alps to the north, just as the north to south chains of Asia are spurs formed in consequence of the elevation of the mountain axis of Asia. North of the Alps other chains at right angles to the main chain, as though they were spurs, slope towards the North Sea, though the plain of North Germany is now raised too high for the water to divide them into peninsulas.

The Vosges and the Schwarzwald both run northward, and the Böhmerwald may perhaps be regarded as another range placed as though it were a northern spur of the Alps; just as the Sudetic Alps and Riesengebirge are parallel chains lying farther north and dependent on the Carpathians, but more denuded, and of older origin. The irregularities of direction of the chains and their deflections are governed, it would seem, by the directions of more ancient mountains which interfere with the flexures of newer date. And it would even seem that mountain chains of ancient date parallel to each other may come to play the part of spurs to a newer mountain range.

It might be reasonably urged that, in the same way that lateral spurs, running north and south, are given off by the Alps, so the mountain systems of Europe and Asia are to be regarded as a grand series of chains which are similarly dependent upon the more ancient disturbances which originated the Ural chain and Caspian Sea. The mountain system of Central Asia, however, presents this remarkable difference from that of Europe, that whereas the western region is broken by the predominant synclinal depression of the Mediterranean valley, the eastern portion has the corresponding area entirely upheaved, so as to constitute the great tableland between Turkestan and China, limited by the Himalayas and the Altai Mountains. The distribution of mountains in Asia shows that the peninsulas which run south are the effects of the formation of lateral chains, crumpled up at right angles to the grand upheaval of the mountain axis to the north, and in consequence of that upheaval.

This predominant direction of so much of the land of the Old World, in an east to west line, is no less remarkable than the corresponding direction of the remainder of the land of the world from north to south; but these different directions of land masses are to be regarded as mutually dependent, in the same way as a mountain chain and its spurs. If we crumple the surface of one side of a globe into ridges running east and west, the material of the crust is so used up by the contractions that no corresponding series of ridges having the same direction could be developed on the opposite side of the globe, for the reason that we have already indicated in explaining the origin of lateral spurs. But since the ridges running east and west do not use up on a large scale material of the earth's crust in an east and west direction, it follows that the predominant contractions which are formed on the opposite side of the globe must develop mountain ridges running from north to south. Thus the Andes and Rocky

Mountains, with the Alleghanies and Cordilleras of Brazil, may be taken as skeleton contours, which are correlative with and dependent upon the formation of the axis of the Eurasian continent; while the north to south mountains of the east and west sides of Southern Africa, of Madagascar and Australia, show that a wide extension of land from west to east about the northern parts of the world cannot be upheaved without the development of correlative elevation in an opposite direction, so as to use up a corresponding portion of the earth's crust on the opposite side of the earth in the direction of tension, which initiates contraction at right angles to itself. Hence, the east to west direction of the Great Antilles is dependent upon the north to south direction of the Andes. The deflection of Central America north-west is governed by the direction of the Appalachian chain north-east. The Suliman mountains and Ghats have a like dependence upon the Himalayas. The existence of the oceans we take to follow the same law as inland seas or other basins, and to be dependent on the contractions which have upheaved the continents.

We have entered into this statement concerning mountains because the views enunciated seem to show an indication of law in the distribution of land and water at the present day. Hence it may be inferred, perhaps, that such a law has never been absent from the earth; and that in its natural development we find an interpretation of the great geological mystery of upheavals and depressions, which caused the same region of the earth in past ages to have been occupied successively by ocean and by land. It harmonises the evolution of mountains by the radiation of the earth's heat, under the principle that pressure of contraction must give rise to tension at right angles to the contraction; and that all chains are hence approximately at right angles to each other, and therefore succeed each other in this order, both in space and in time.

A mountain chain once formed can never be obliterated or ignored by a newer chain crossing the same district; and the rocks of the folded region, no matter how denuded or depressed, will always exhibit the conditions of their origin. In such a sense mountains and continents may be said to be permanent; but just as the formation of the great east to west ridges of the mountain axis of the Old World drew the land up above the ocean to the north and south, in Tertiary times, so we may anticipate that the line of contraction which is outlined in the Dolphin and Challenger ridges would by further elevation gradually draw the lands on both sides of the Atlantic beneath the sea, and vary the geography of the world much as it has changed in bygone times. In successive ages the great contractions of the earth's crust are repeated, and upheaval and depression take place in later ages along old lines of contraction; but contraction in one direction may be succeeded in the next period of geological time by a contraction which is approximately at right angles, resulting in grand unconformity of the newer strata, because the origin of rock material is different.

CHAPTER XX.

METAMORPHISM.

SUBTERRANEAN heat has transformed to a certain extent strata of all ages which were exposed to its action; and thus the Lias shale of Savoy, for example, approximates to the character of clay slate. In such cases, we may indicate the alteration by Lyell's term *metamorphic*, and designate by it all those parts of aqueous strata which have been transformed in structure or appearance by subterranean heat, or heat developed by pressure applied since their deposition. All strata may become metamorphic.

Effects of Internal Heat.—We have seen the effects produced by plutonic rocks upon strata which they penetrate; these effects depend on the degree of heat communicated, and the substances operated on. As examples of these effects we may name structural metamorphism, molecular metamorphism, and chemical metamorphism:—

1. The *consolidation* of stratified rocks is exemplified in the induration and contraction of shale, and in the development of new faces or joints in it, which sometimes meet one another rhomboidally, sometimes follow the columnar relations of the adjoining basalt, and sometimes imitate slaty cleavage.

2. The *partial fusion* or cementation of some part of the substance of a rock, so as to agglutinate its grains and solidify and harden the whole mass. Thus sandstone is converted to a granular quartz rock.

3. The complete vitrification or recomposition of the rock, thus converting shale into Lydian stone, and fine sandstone into a kind of jaspar, or even into schists or igneous rocks.

4. The complete rearrangement of the particles into granular or crystalline forms, as in the instance of chalk in Ireland, and limestones in Yorkshire, the Isle of Skye, and Carrara.

5. The production of minerals not before existing in a distinct state in the substances affected. The development of pyrites, asbestus, anthracite, plumbago, garnet, &c., along the contact of igneous and aqueous rocks is a very characteristic and general effect, which appears to result from the actual transfer of the metallic and other matter through the solid substance of the rock. If Von Buch's notion of the impregnation of strata with magnesia in the vicinity of augitic rocks should be substantiated, it must be considered as a remarkable example of such transfer of mineral material.

6. The sublimation of some portion of the neighbouring substances. Thus the charring of coal, the expulsion of sulphur and bitumen from shale, are directly connected with the heating power of the igneous rock. It is probable that some peculiar conditions were required for such effects of contact metamorphism in submarine depths, where most of these operations were performed.

Metamorphism of Rocks.

Structural Metamorphism.—In daily experience, we see some degree of consolidation effected in calcareous deposits by the concretionary or crystalline coherence of the particles. But we scarcely perceive any induration of clay or agglutination of sandstone without infiltration of salts, enormous pressure, or the application of heat. By the subsidence of the strata to some thousands of feet or yards, which has unquestionably happened in very many cases, these favourable influences were brought into action. The oldest strata were upon the whole sunk to the greatest depth, and in consequence have experienced the greatest amount of pressure and heat, and these are on the whole the most consolidated; the clays have become slate and the sands quartzite.

Effects of Pressure.—The lowest strata of the coal basin of South Wales, which were deposited nearly at the sea-level, were necessarily sunk during the latest palæozoic periods about 12,000 feet below the surface. In these a partial slaty cleavage appears. The Old Red Sandstone strata, several thousand feet thick, which were still deeper and more heated, are more marked by cleavage; and the Silurian and Cambrian, still deeper by thousands of feet, are even more distinguished by that structure. It is chiefly in what were the deeper parts of the basin that this effect occurs; for on the north side of the South Wales coal-field the Silurian strata and the Old Red Sandstone are often free from cleavage, and cleavage is there only partially exhibited in the Cambrian.

Farther to the north, as in the district of the Malvern Hills, Woolhope, Abberley, Dudley, the Silurian rocks and all above them are free from cleavage, or exhibit it only in a very slight degree, and along some small and limited spaces. Yet these districts are marked by great and violent flexures, and even reversals of the strata, so that *pressure* seems sometimes to have failed entirely in producing cleavage. This is the more curious, because, in the same country, parallel to the once heated basalt dyke of Brockhill, the Old Red Sandstone shales have developed a rude cleavage. In these districts there is no reason to admit more than 5000 to 8000 feet of depression.

The Cambrian rocks of Charnwood Forest and the base of Ingleborough are full of cleavage, crossing great curvatures of the strata. Those curvatures preceded the formation of the Old Red Sandstone. There is no cleavage in any of the upper or middle palæozoic strata, which, in the utmost depression which we can trace, may have been sunk some 5000 or 6000 feet deep in Yorkshire, and some 8000 feet

deep in Lancashire; but the Cambrian and Silurian rocks in which cleavage occurs must have been depressed twice as deep.

From considerations of this kind we are led to admit that depth in the earth—that is, the heat, and pressure, and molecular action favoured by depth, and of which depth is a measure—is one of the main agencies favourable to the generation of slaty cleavage in the strata. *Pressure* is clearly necessary. For the direction of the planes of cleavage is parallel to the great axis of movement in the district which determines the strike of the rocks; and Professor John Phillips's researches, enlarged by the investigations of Mr. Sharpe, left no doubt that the compression of the rocks is in the direction at right angles to the cleavage planes. Mr. Sorby succeeded in producing cleavage structure by artificial pressure in clay originally quite destitute of it. Some further illustrations were added by Dr. Tyndall, who used pressure to develop cleavage in wax. Hence we arrive at the following general view. A *large area* of country subsides parallel to a certain axis of movement, is thrown into parallel folds, and is transferred to a hotter and narrower space—hotter as compared to the surface, narrower as the chord is shorter than the arc. Lateral pressure operates on all the strata; heat more particularly on the argillaceous parts; plates of mica become scattered through these strata, and are by the pressure made to assume positions which are not all parallel, but tend to parallelism, and thus effectually cause fissility in the stone.[1]

Cleat.—Though there is no slaty cleavage in the coal strata of the northern counties, or indeed in Wales, there is a structure called "cleat" in the substance of coal which is of the same order, quite as regular and extensive, and due to as general a cause. This consists in a series of parallel fissures, often very fine and numerous, which cut across the strata of coal in planes nearly vertical to the strata, and in directions seldom deviating much in the large area of a coal-field. In the northern coal-fields this direction is N.N.W. and S.S.E., or nearly so. It scarcely occurs except in the coal, is not affected by faults, is not parallel to axes of movement, and varies in character from bed to bed. This structure is of a very peculiar type in the anthracite of Wales.

Cleavage on Mont Blanc.—In a survey of the structure of Mont Blanc,[2] Mr. Sharpe traced no fewer than nine parallel axes of slaty cleavage, crossing the gneissic, calcareous, and argillaceous strata, which dip in various directions, a phenomenon analogous to that observed by the same geologist in the country of the Highlands.[3]

Molecular Metamorphism.—Under this head we class the conversion of earthy carbonate of lime into crystallised marble, which has been effected naturally, by the proximity of igneous rocks, in many places, as in Teesdale by the basalt or whin sill, in Raghlin by basaltic dykes, and artificially by Sir James Hall in a heated gun-barrel. On a large scale, saccharoid limestone is a great example, proving the pervading influence of high heat through a mass of deep-

[1] Sorby, in Q. J. G. S., &c. [2] Geol. Proceedings, 1855. [3] Phil. Trans., 1855.

seated rocks, by which the carbonic acid was retained in them and the particles of the rock entirely rearranged. Similarly the change of loose sand or argillaceous sandstone to solid sandstone or quartzite, or jasper, or rhyolite, or granite, is, in the first place, a case of cementation of the grains through heat, followed by gradual solution of the rock in the water which it contained, and more or less perfect crystallisation, by which in many cases twin crystals of highly complex structure have been formed by the enlargement and blending of crystals which were at first microscopic. In the consolidation of clay slate, the particles are not merely pressed together, but more or less confluent at the edges, from crystallisation,[1] and in basalt and basaltic dykes we see a more perfect development of molecular metamorphism.

Stages in Chemical Metamorphism.—The most extreme change induced by heat, and the chemical actions which heat and water acting under pressure set up, is an alteration in the nature of a rock. Such a case, in its simplest form, may be typified by the generation of garnet in the vicinity of dykes and large igneous masses, or in the artificial combinations of the furnace. Near the dyke of Plasnewydd, in Anglesea, Professor Henslow collected in the altered and jasperised shales grey garnets; in the rock of the mountain called the Gable, near the granites of Wast Water, are multitudes of beautiful red garnets. We are thus led by easy analogy to view the innumerable garnets in the mica slate of the Highlands as generated in those foliated rocks by chemical combinations which originated under the same influence of heat, as that by which the limestone which lies in them has become crystalline, and by which the schists have acquired their granitoid aspect.

Ratio of the Metamorphism of Strata.—On considering the series of strata in relation to the degree of their metamorphism, it is impossible not to perceive that in most countries metamorphism increases continually with the age of the rock. It is impossible at present always to point out exactly the amount of changes which have been produced on the primary strata by the general and continued communication of heat from below; gneiss, for example, is in some cases almost identical with granite, in other cases approximates to sandstone. Yet when we consider the bedded and laminated character of this rock, and observe that its constituent minerals, even when united into a dense rock, are not crystallised with regular external forms, successively modifying one another in a certain order, we understand that the rock has been solidified by a species of crystalline growth at the edges of the constituent substances, which, carried to extreme, under the requisite pressures, would have reconverted the whole into granite.

Similar remarks apply to mica schist, which, on the one hand, varies to gneiss, and on the other to clay slate; and it is observable that the fusible mineral garnet, which is generated at moderate heats in rocks in contact with basalt, is very generally intermixed with the laminæ of gneiss and mica slate.

[1] Sorby, Address Geol. Soc., 1880, p. 47.

The limestone of Teesdale is a hard rock, but where it touches the basalt of that country it has become crystalline. The shales are also altered (fig. 70, p. 337). The upper portions of the slate system in Shropshire and Radnorshire, where that system is immensely thick, show similar changes.

Decreasing Effects of Pressure and Heat in Newer Strata.—The effects of general pressure and heat continually decrease among the superior strata of the Saliferous, Oolitic, and Cretaceous systems, and seem almost wholly lost in the tertiary strata of this country. It is chiefly to this graduated effect of heat that we may ascribe the distinctness of the rocks in different parts of the series. Thus, to take the calcareous rocks, we have a series gradually changing in proportion to their antiquity, from crystalline limestone, through highly condensed carboniferous limestone, to compact lias, concretionary oolite, marly chalk, and tertiary lacustrine marls. Among sedimentary deposits there is a series from gneiss through the hard sandstones associated with the carboniferous limestone to the sands of the oolites, chalk, and tertiaries; and another series from cleavable slate, through jointed greywacke slate, hard coal shale, compact red marl, lias and lower secondary clays, gault, and clays of the tertiary period. There is properly no sand, clay, or marl among the older strata. Indurated shale, hard gritstone, and compact limestone are of rare occurrence among the younger rocks.

Effects of Heat in forming Granitoid Strata.—Mr. Sharpe regarded the foliation of gneiss generally as due to metamorphic action of the same kind as that which produced cleavage in slate, only more prolonged and more intense, and this view is now generally accepted.

These foliated rocks, which have the aspect of being derived from decomposed granitic rocks, with subordinate and associated strata equally devoid of organic remains, constitute, according to the testimony of observers, the lowest geological group, and in most countries were originally water-formed deposits. From the effects of metamorphic agents upon these rocks, their natural analogy to granite is sometimes so much heightened as to cause some uncertainty in distinguishing between them, and enforce a conviction that the distinction between them is one of degree, and not of kind. The rocks of this whole series might without impropriety be termed *granitoid strata.*

Foliation.—Foliation is certainly in most cases independent of stratification, and Darwin observes that even when its direction corresponds to the strike of strata its dip is different. David Forbes records at Crianlorich in Perthshire, beds of blue limestone resting on mica schist, but with the limestone foliated by the development of plates of mica so as to resemble gneiss; and while the foliation in the limestone appeared to be identical with the planes of bedding, in the bed above the limestone the foliation is twisted and irregular. At Jaegerborg near Christiansand foliated limestone abounds, and contains patches of gneiss, besides being capped with gneiss, which is itself capped with granite.[1]

[1] Q. J. G. S., vol. xi. p. 167.

Mineral Constituents of Metamorphic Rocks.

Any theory of relation between metamorphic rocks and plutonic rocks must be based upon similarity in the composition of constituent minerals in the rocks which are compared. Interesting researches made by Professor Heddle show absolute correspondence between the metamorphic and plutonic forms of minerals [1] in the same district. And if any theoretical value is to be attached to the chemical composition of different rocks, the tables of composition of the chief minerals which we reproduce will go far to show within what limits a rock may vary in chemical composition owing to the proportions in which its mineral elements are combined.

Felspars.—Orthoclase is found in gneiss at Glen Urquhart, Deeside, and central Sutherland associated with hyaline quartz, carrying Lepidomelane or Haughtonite, and occasionally apatite. In chlorite schist it is associated with chlorite and rutile. It is occasionally found in porphyry, and exceptionally in syenite, as on Morven and Froster Hills, and near New Leslie in Aberdeenshire associated with hornblende, menaccanite, and sphene. More rarely it is found in crystalline limestone. Orthoclase enters into a greater number of rocks than any other felspar.

Albite has only been found in Scotland in the red granite of Peterhead, which contains hornblende and epidote; and in another hornblendic and serpentinous rock from Fetheland Point to Hillswick Ness in Shetland. It forms the moonstone of Stromay.

Anorthite or lime-felspar is recorded in the diorite of Fetlar, and some parts of the gabbro of Ayrshire, but is not a felspar found in limestones.

Latrobite, the lime-potash felspar, is found in the crystalline limestone of Glen Gairn.

Labradorite is nowhere found in Scotch metamorphic rocks, being limited to gabbro, diallage rock, and dolerite.

Oligoclase combined with hornblende forms the hornblendic gneiss of Cape Wrath, and makes the bulk of the grey granite of Aberdeen, where it is associated with a little orthoclase, a little quartz, a little muscovite, and much Haughtonite, forming the compound termed granitite.

Andesine is in Scotland a characteristic felspar of gneiss, just as oligoclase is characteristic of granite. Andesine is especially found in limestone.

These felspars are practically identified with the microscope, in thin sections under polarised light, by the angle between the directions of "Extinction" of adjacent laminæ. When the angle exceeds 62° 30′ the felspar is Anorthite. If the angle is between 37° and 62° 30′ the felspar is probably Labradorite. If the angle is less than 37° it may be Oligoclase or Albite.[2]

[1] M. F. Heddle, Mineralogy of Scotland. Trans. R. S. Edin., vols. xxviii. and xxix.; and Journ. of the Min. Soc., vols. ii., iii., iv.

[2] Fouqué and Lévy, Roches Éruptives Françaises.

COMPOSITION OF ORTHOCLASE IN SCOTCH ROCKS.

Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Manganese.	Magnesia.	Lime.	Potash.	Soda.	Water.
Ben Capval	Granite dyke in gneiss	Blue	64·86	18·47	·67	..	·71	..	12·98	1·89	·5
Stromay, Harris	Dyke	Grey	65·35	17·68	·92	..	·25	·68	13·13	2·5	·18
Glen Fernate	Granite vein in mica slate	Pink	63·99	17·06	2·47	..	·07	·52	14·85	·53	·65
Cowhythe, Portsoy .	Granite veins in talc slate	Flesh	64·74	18·3	1·99	..	·04	·97	9·87	3·34	·17
			66·0	18·3	2·03	..	..	1·	10·02	3·19	·16
Clattering Briggs . .	Dyke of red porphyry	Fawn	64·03	19·17	·3	·22	·94	1·4	11·84	1·37	·57
Rubislaw .	Veinstone in granite	Flesh	64·54	18·36	·32	..	·09	·36	13·05	2·58	·09
Lairg. . .	Veinstone syenitic granite	Buff	62·62	19·63	·06	..	·64	·6	13·72	2·92	·13
Tongue . .	Amazon stone vein in syenitic granite	Green	64·2	18·39	·45	·15	·07	·72	12·75	2·95	·51
Froster Hill	Syenite. . . .	White	63·31	18·17	·87	..	..	1·07	13·27	2·06	·81
Blirydrine .	Micaceous gneiss	White	63·59	19·58	1·09	..	·08	·68	12·53	2·76	·42
Banchory .	? Granite	White	63·11	18·98	·98	..	·57	·88	13·06	2·34	·34
Balvraid .	Crystalline limestone	Blue	63·04	19·31	..	..	·21	·97	14·63	1·02	·56
Struay, Ross . .	Granite band in gneiss	Pink	65·	17·03	1·43	·69	..	·73	13·82	1·	·50
		Blue	64·19	17·39	1·2	·46	..	·69	13·31	1·96	·56
Canish, Sutherland	Porphyry in quartzite	Brick	63·54	17·36	1·87	·38	..	1·33	12·93	1·69	1·12
Sanidine, Corriegills .	Pitchstone porphyry	Colourless	66·85	17·24	·42	..	·06	1·22	9·2	4·32	·86
Kinkell . .	Tuff	Yellow	63·07	18·68	2·47	·06	..	2·2	6·62	5·5	1·39

COMPOSITION OF ALBITE IN SCOTCH ROCKS.

ALBITE, OR SODA FELSPAR.										
Locality.	Rock.	Colour.	Silica.	Alumina.	Ferrous Oxide.	Magnesia.	Lime.	Potash.	Soda.	Water.
Stromay, Harris	Granite dyke in hornblendic gneiss	Grey .	66·97	19·46	·6	·21	2·04	1·23	9·54	·31
Colafirth, Shetland . .	Serpentine and talc rock	White	66·8	17·83	1·13	·14	1·5	·92	11·52	·48
Colafirth . .	"Quartz vein"	White	66·84	16·73	2·42	·37	·94	·73	10·76	·89
Hillswick . .	In hornblendic rocks	Pink .	66·71	19·81	·9	·09	1·38	1·26	9·23	·54
Cleavlandite, Ben Bhreck, Tongue	Veinstone in syenitic granite	White	67·79	18·76	1·43[1]	..	·52	·76	10·49	·16

[1] Fe_2O_3, also ·08 Mn.

OLIGOCLASE: SODA LIME FELSPAR.			Silica.	Alumina.	Ferric Oxide.	Manganese.	Magnesia.	Lime.	Potash.	Soda.	Water.
Locality.	Rock.	Colour.									
Rispond, Sutherland	Granite vein in hornblendic gneiss	White	61·85	21·7	3·37	·2	·09	4·13	1·63	6·95	·37
Coyle, Aberdeen	Actinolite slate.	Cream	63·54	21·45	1·86	..	·23	3·88	1·07	7·64	·44
Barra Hill, Old Meldrum	Black serpentine	Milk .	64·67	22·18	1·44	..	·01	1·89	1·54	7·62	·15
Dyce, Aberdeen	Veinstone in grey granite	White	64·85	23·2	..	..	·2	·96	3·77	8·12	·01
Sclatty, near Buxburn	Granite vein. .	White	59·53	21·05	1·81	..	·88	3·63	4·73	7·23	1·88
Rubislaw .	Veinstone in granite	White	62·53	23·52	1·28	..	·36	4·97	1·32	6·19	·6
Craigie Buckler, Aberdeen	Granite . . .	White	61·58	22·	1·28	..	·32	4·19	1·52	8·27	·54
Lairg. . . .	Vein in syenitic granite	Colourless	62·81	22·92	·16	..	·08	4·25	·84	8·53	·29
Canisp . .	Porphyry. . .	Cream	64·44	20·47	·88	·38	..	1·3	1·13	9·96	1·46

COMPOSITION OF SCOTCH ANDESINE.

ANDESINE: LIME AND SODA FELSPAR.			Silica.	Alumina.	Ferric Oxide.	Manganese.	Magnesia.	Lime.	Potash.	Soda.	Water.
Locality.	Rock.	Colour.									
Glen Urquhart .	Crystalline limestone	White	58·38	22·5	2·12	·15	tr.	5·34	3·2	5·21	3·41
Glen Gairn, Aberdeen. .	Crystalline limestone in gneiss	Blue .	57·18	24·04	1·12	..	·12	6·11	2·83	7·13	1·6
Glen Gairn . .		White	56·96	23·81	·94	..	·09	7·98	2·56	6·85	1·62
Crathie . . .		White	56·3	25·71	·97	tr.	—	9·35	1·49	4·72	1·82
Portsoy. . . .	? diabase . .	White	58·36	23·34	·24	..	·5	8·24	1·15	7·84	·53

COMPOSITION OF SCOTCH LABRADORITE.

LABRADORITE: LIME SODA FELSPAR.			Silica.	Alumina.	Ferric Oxide.	Manganese.	Magnesia.	Lime.	Potash.	Soda.	Water.
Locality.	Rock.	Colour.									
Portsoy (massive)	Gneiss . .	White .	53·03	29·85	·13	..	·61	11·44	·64	4·21	·42
Loch Scavaig .	Gabbro . .	Grey . .	50·81	29·48	·25	..	·12	12·69	·55	3·92	2·48
Glen Bucket .	Diorite . .	White .	50·59	28·33	3·05	..	·59	11·17	2·18	2·56	1·42
Balta	Gabbro . .	White .	53·14	29·99	·25	..	·21	12·3	·47	3·86	·21
Portsoy (crystals)	Gabbro . .	Grey . .	52·41	28·96	·15	·91	·54	10·85	1·61	3·48	·93
Kildrummy .	Mica-Gneiss	Cream .	51·31	26·76	1·82	·76	·41	10·14	2·11	6·43	·68
Kinneff . . .	Porphyrite	Colourless	53·19	26·43	2·85	tr.	·92	9·68	1·51	4·59	·73
Balvraid, Glenelg	Serpentinous limestone	Wax	47·44	28·02	·34	..	·41	11·03	3·51	4·61	5·23

Anorthite, or Lime Felspar.												
Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Magnesia.	Lime.	Potash.	Soda.	Water.
Fetlar, Shetland	Anorthite diorite	Cream .	46·92	30·77	..	..	tr.	·09	16·34	1·5	3·07	1·54
Lendalfoot, Ayr	Gabbro	Greyish	44·22	31·44	1·95	..	·..	1	14·18	1·48	1·63	3·69
Delnabo, Glen Gairn	Crystaline limestone	Green .	46·42	21·86	..	5·92	·69	2·92	18·38	1·26	1·69	1·08

Latrobite, or Potash Lime Felspar.												
Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Magnesia.	Lime.	Potash.	Soda.	Water.
Delnabo, Glen Gairn	Crystaline limestone	Rose .	45·2	31·04	3·43	tr.	·68	1·2	5·21	7·12	·49	5·7
		Rose .	46·87	29·31	2·31	·11	1·15	1·38	6·46	7·31	·85	4·49

Micas in Metamorphic Rocks.—Muscovite, according to Professor Heddle, is chiefly found in granite veins, which he terms "exfiltrative veins," but which we regard as vein-stones. Such veins, remarkable for their tortuous course and branches, were by Jameson and the older writers termed contemporaneous veins. Muscovite is specially cited from the great vein of Capval, in Harris, where an abundance of ferrous oxide gives it a green colour, though the finest specimens are known from Bigsetter Voe, in Mainland, Shetland, and Glen Skiag and Loch Glass, in Ross-shire. This mica is comparatively rare in granite in Scotland. Margarodite is another potash mica, but with more soda; it is characteristic of gneissose rocks, specially in Shetland, but it occurs in granular limestone in Aberdeenshire, Banff, and the central parts of Scotland.

Of the black micas, biotite is characteristic of crystalline limestones, no other mica occurring in them in Scotland except margarodite. Among the well-known localities for it are Glen Urquhart, Glen Laggan in Inverness, Shinness in Sutherland, and Glen Beg in Glenelg. Lepidomelane is another black mica, found in gneiss on the north shore of Loch Shin, in Sutherland. Its colour is yellowish-brown to chocolate-brown. This is the ordinary black mica of the granites of Ireland. A blacker mica is Haughtonite, remarkable for its large percentage of iron. It is found in veins in hornblendic gneiss, in the graphic granite which occurs in the gneiss, at Rispond, Sutherland, and in the micaceous gneiss of many localities in Ross and Sutherland. This mica is frequently associated with oligoclase, especially in veins, but it is an essential constituent of grey granite,

which Heddle states to be formed of oligoclase, quartz, and Haughtonite, with some orthoclase. It is considered likely that lepidomelane is the dark mica of some gneisses, such as the bronzy gneiss of Tiree, while Haughtonite occurs in others. Haughtonite is readily distinguished from biotite under the blow-pipe, since biotite whitens, and Haughtonite increases in blackness.

WHITE MICAS.

Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Potash.	Soda.	Fluorine.	Water.
Margarodite.													
Lambhoga	Kaolin in gneiss.	Faint yellow	50·77	31·71	1·32	..	·23	·95	·79	5·11	·52	..	7·97
Vanleep, Shetland	With kyanite in quartz vein in mica gneiss	White	45·43	29·65	8·33	..	·02	·79	1·7	6·94	2·27	..	5·29
Vanleep, Shetland	In mica-slate	White	45·42	30·30	6·87	..	·82	·6	2·6	6·09	2·01	1·06	5·01
Botriphine, Banffshire	With kyanite	White	45·1	29·9	7·87	..	·03	·62	·72	7·84	2·56	tr.	5·51
Glenbucket	Crystalline limestone	White	46·18	31·83	4·1	..	..	1·66	1·23	8·81	1·31	..	5·71
Muscovite.													
Ben Capval	Granite vein	Green	43·08	32·85	·73	2·76	·08	1·07	·33	9·08	·84	..	9·12

BLACK MICAS.

Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Potash.	Soda.	Fluorine.	Water.
Biotite.													
Glen Urquhart	Crystalline limestone in gneiss	Pinchbeck brown	38·69	17·66	·25	12·95	...	1·16	17·54	8·92	·13	·52	2·14
Laggan	Limestone	Bronzy	39·5	15·04	·24	10·23	·75	1·4	18·46	9·37	·62	·73	3·21
Shinness	Limestone	Brown black	39·77	16·68	·65	6·73	·62	2·2	20·92	6·5	·48	..	5·4
Glen Beg	Limestone	Chocolate brown	39·46	16·45	·39	10·	·53	1·59	19·	8·22	·26	·32	3·34
Hillswick	Hornblendic gneiss	Bronzy brown	39·8	14·19	2·59	11·58	·24	·1	18·32	8·43	2·11	·56	2·52
Milltown, Urquhart	Edenite rock	Very pale green to rich brown	40·31	12·58	1·81	3·35	·38	7·58	21·	6·56	·95	..	5·74
Lepidomelane.													
Achadhaphriz	Gneiss	Brown	40·38	12·11	14·53	3·03	3·17	1·03	13·	7·13	1·8	..	3·57
Tongue	Vein in granite	Deep brown	40·08	12·41	13·47	2·67	·62	1·08	14·66	7·57	2·15	..	5·29

HAUGHTONITE.												
Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Potash.	Soda.	Water.
Roneval, Harris	Granite vein	Black brown	37·16	15·	7·69	17·35	1·04	1·3	8·88	8·18	1·6	2·12
Loch-na-Muilne, Lewis	Granite vein in gneiss	Brown to black	36·46	17·25	4·18	15·33	·54	·69	12·23	9·2	·66	3·39
Rispond, Sutherland	Gneiss	Deep black	36·54	22·28	2·43	16·01	·78	1·25	10·	8·26	·79	1·96
Kinnaird Head	Vein in gneiss	Black: films	35·67	17·95	7·19	18·06	2·	1·4	1·5	9·27	3·81	3·2
Lairg	Vein in syenitic granite	Dark green	35·56	16·69	1·88	18·04	·69	2·72	8·47	9·9	·11	5·71
Portsoy . . .	Diorite	Bronzy brown	34·08	17·34	3·61	18·70	·38	3·23	10·54	6·78	1·19	4·05
Ben Stack . .	Granite	Brown black	35·69	20·09	2·23	14·01	1·	1·89	14·77	7·38	·53	2·46

Chlorites are essentially metamorphic minerals, and according to Heddle, the true chlorites never occur in volcanic rocks, while the saponites are confined to volcanic rocks. Chlorite has been found in granite at Rubislaw and at Girdleness. The chlorites comprise glauconite, talc chlorite, penninite, ripidolite, chlorite, and chloritoid. They often have a cryptocrystalline structure, so that they are only to be identified by chemical or external characters. Penninite is found in serpentine in hornblendic gneiss in Scalpa, Harris, in the mica schist of Glen Lochy, in Perthshire, and in Shetland. Ripidolite is found in limestone, in mica slate, in chlorite slate, and in hornblendic gneiss, especially at Cape Wrath. Chlorite is found in serpentinous beds, in micaceous gneiss which is free from felspar. It occurs in the mica slate which ranges from north-east to south-west through the lower Highlands of Scotland, in granular limestone parallel to the limestone of Glen Tilt, and in chlorite slate to the west of Portsoy, in Banffshire. Chloritoid is a Shetland mineral, as is talc chlorite; both are found near Hillswick.

The saponites comprise Delessite, chlorophæite, Hullite, saponite, and seladonite. They may be regarded as decomposition products, and in that sense as metamorphic, but there are no British metamorphic rocks, properly so called, in which they form an important constituent. Delessite abounds about Dumbuck; it has a dull lustre and dark colour. A variety in the tufa at Elie Ness contains 5 per cent. of soda and 3 per cent. of potash; like saponite, it always contains about 20 per cent. of manganese. Chlorophæite, when fresh, resembles a green jelly, when weathered it resembles drops of asphalt; it contains less alumina, the iron is chiefly ferric oxide, instead of ferrous oxide; the magnesia is reduced to one-half, and the water is half as much again. Saponite is soft, greasy, green, and translucent; it is richer in silica and poor in alumina; the iron is small in quantity and the water large. The saponites are regarded as products of the decomposition of augite and olivine.

CHLORITE.

Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Potash.	Soda.	Water.
Fethaland, Shetland	Mica gneiss	Bright green	24·3	20·86	3·57	16·72	·55	·5	22·2	..	..	11·55
Ben Derag, Perthshire	Mica slate	Grass green	24·72	21·57	·62	26·16	·47	·45	12·86	1·73	·05	10·89
Craig-an Lochan	Mica slate	Dark green	24·29	21·18	·10	18·74	·8	1·66	21·03	1·29	·56	10·08
Lude . . .	Lime-stone	Olive green	23·92	22·98	1·11	19·54	·28	2·45	17·26	..	..	11·78
Lude . . .	Lime-stone	Bright green	24·66	23·19	·64	20·58	·29	·4	17·79	..	..	12·12
Portsoy, Banffshire	Chlorite slate	Bright green	26·71	20·42	3·47	13·99	·73	..	23·9	..	..	11·17
Loch Laggan, Inverness-shire	Lime-stone	Grass green	26·25	19·22	1·67	16·44	1·02	..	24·35	..	..	11·67
Girdleness, Kincardine	Granite	Dark green	24·77	20·16	1·38	27·39	·61	·9	13·34	..	..	12·05

Augite and Hornblende in Metamorphic Rocks.

The varieties of augite and their alteration products are frequently met with, though they are scarcely so important as the minerals of the hornblende group. Crystalline or granular limestone is rich in the paler coloured varieties of both minerals. Malacolite, which is a white or blue variety of augite, forms layers in the limestone of Loch Shin, in Sutherland, crystals often being a foot long. The limestone of Totaig, which is embedded in micaceous gneiss, is full of nodules of it. It is found in the limestone of Glen Tilt, and near Serpentine in the hills of Coyle, in Aberdeenshire. The sap-green variety of sahlite is often associated with malacolite. Sahlite is well known from the marble of Tiree, which is characterised by numerous minute crystals of the dark-green variety, about the size of shot. Another of these augitic minerals is coccolite, of a deep rich green colour. Diallage is recorded from the diallage rock of Unst, in Shetland, where the crystalline masses of diallage are embedded in fine granular labradorite. It is also recorded by Professor James Geikie at Pinbain, near Lendalfoot, in Ayrshire. True augite does not occur in the metamorphic rocks of Scotland, though it is found in the volcanic rocks of Rum and Skye.

Augite and hornblende, in Scotland, are both connected with the formation of serpentine. Heddle states that the serpentines of Unst, in Shetland, are derived from diallage; that one of the beds to the west of Portsoy is derived from gabbro, and the other from eupotide; while the bed to the east of Portsoy is derived from an augitic rock. The same author states that a bed of serpentine in the Farrid Head, Sutherland, is unquestionably derived from gneissic schists.

Among hornblendic minerals asbestos is plentiful in the granular

limestone of Shinness, where tremolite also occurs, forming crystals nearly a foot long. The magnesia lime amphibole, called edenite, is found in the localities already alluded to—Milltown, Glen Urquhart, &c., which have yielded so many minerals in the granular limestone. Actinolite, on the other hand, is characteristic of hornblendic gneiss, especially at Hillswick, in Shetland, and typical hornblende has been found by Heddle on the north-west of Ben Spinna in Durness, but hornblende is rather associated with the diallage rocks of Shetland and the diorite of Portsoy. Like augite, it undergoes the usual alterations by taking up water, peroxidation of the iron, diminution of the lime, and partial removal of the silica, all these changes being attributable to the action of waters passing through the earth.

By means of the following tables the varieties of Amphibole and Pyroxene may be contrasted; but beyond the fact that Amphibole usually contains rather more magnesia and less lime, there is no striking difference in composition; and it would not be possible to estimate the chemical composition which would give rise to one variety rather than another if a sedimentary rock were metamorphosed. The evolution of these minerals seems to depend upon the other mineral constituents developed in the process of crystalline change.

Pyroxene.													
Mineral.	Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Potash.	Soda.	Water.
Malacolite.	Shinness	Limestone .	White	53·06	·19	1·77	·47	·15	23·63	19·29	..	..	1·54
	Totaig .	Limestone in mica gneiss	Blue .	50·69	·03	·93	..	·07	25·78	18·09	·5	1·43	2·62
	Glen Tilt	Limestone altered by granite.	White	53·24	..	2·71	..	·13	22·77	18·86	..	..	2·18
	Glen Muick, Coyle	Serpentine .	Blue .	51·	..	1·37	1·59	·38	26·36	17·08	·63	1·12	·26
Sahlite.	Ben Chourn	Granular limestone	Leek-green	54·48	..	..	3·13	·24	22·82	17·58	·44	·79	·42
	Tiree .	Marble. .	Dark-green	50·54	4·69	4·14	·08	·69	23·59	14·4	·31	·63	1·48
	Eslie .	Limestone .	Grass-green	49·5	1·96	..	11·06	·4	24·08	10·81	·57	·8	·69
Diallage.	Balta .	Metamorphic diallage rocks	Grass-green	50·23	5·84	..	5·22	..	11·23	21·59	1·2	·58	4·17
Augite.	Glen Beg	Limestone .	Dull-green	54·22	·17	..	6·7	·4	19·57	16·97	·5	·45	·96
	Halival, Rum	Gabbro. .	Dull-green	50·54	3·35	1·34	4·42	·23	21·42	17·05	·25	·53	·71

Amphibole.													
Mineral.	Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Potash.	Soda.	Water.
Hornblende	Kyle of Durness	Hornblendic gneiss	Rich green	51·46	2·96	2·45	9·66	1·07	20·07	10·46	·68	1·30	·68
Hornblende	Balta, Shetland	Diallage rock	Dark green	45·86	8·78	..	14·15	·13	9·81	14·4	·82	1·43	2·31
Edenite	Urquhart	Granular limestone	Blue black	51·31	2·21	·16	7.66	·49	11·17	20·87	2·2	·46	2·12
Actinolite	Hillswick	Hornblendic gneiss	Bright green	55·	1·51	·99	3·45	·30	10·38	23·30	1·12	1·09	2·89
Tremolite	Urquhart	Granular limestone	Yellow	57·30	6·67	1·08	3·22	·30	12·36	16·61	..	..	2·5
Tremolite	Shinness	Limestone	Silvery white	56·15	·85	1·61	·71	·06	13·31	24·13	·44	·21	2·5
Asbestos	Shinness	Limestone	Granular limestone	56·86	·23	·48	2·12	·23	12·53	23·92	·43	·53	2·52
Amianthus	Balta	Diallage rock	Grey green	56·15	1·53	·38	3·11	·77	11·71	22·46	·18	·69	2·5

Garnets.—Pyrope or magnesia iron and alumina garnet, though often found in serpentine, is in Scotland only recorded from basalt. It occurs to the east of Elie, in Fife, and is known as the Elie ruby. The common garnet, or iron alumina garnet, is characteristic of micaceous gneiss and mica slate, especially at Killiecrankie, where garnets are of the size of bullets, and embedded in a paste of mica. The almandite is found in the micaceous gneiss of Sutherland; and the precious manganese garnet occurs in granitic belts in micaceous gneiss near Strathpeffer in Ross-shire.

Mineral.	Locality.	Rock.	Colour.	Silica.	Alumina.	Ferric Oxide.	Ferrous Oxide.	Manganese.	Lime.	Magnesia.	Water.
Grossular . .	Creag Mohr .	Limestone	Pea-green	39·83	9·74	15·07	·11	·35	33·57	1·01	·05
Cinnamonstone	Glen Gairn . .	Limestone	Garnet	39·27	21·98	1·49	3 ·93	·33	31·88	·6	·18
Pyrope . . .	Elie	Basalt	Port wine	40·92	22·45	5·46	8·11	·46	5·04	17·85	
Common garnet	Burra Voe, Yell	Gneiss	Pinkish red	37·3	21·1	7·47	24·02	2·14	4·43	3·53	..
Do. do.	Killiecrankie .	Mica slate	Brownish red	37·59	13·66	3·66	32·31	4·47	4·12	3·46	·32
Do. do.	Meall Luidh .	Mica slate	Red brown	37·7	14·8	4·56	32·97	2·37	5·89	1·81	..
Do. do.	Knock Hill .	Diorite	Port wine	37·11	14·9	10·13	32·41	1·21	2·17	2·93	..
Almandite .	Clach an Eòin	Mica-gneiss	Brown red	39·93	19·81	13·69	13·29	1·	9·13	3·31	..
Precious garnet	Glen Skiag . .	Granite in gneiss	Red	35·99	16·[illegible]2	8·64	23·27	15·24	·4	·47	·25
Do. do.	Loch Garve .	Granite vein	Red brown	36·15	21·94	15·15	15·09	7·85	2·07	1·62	·31
Do. do.	Struay Bridge	Granite	Red	35·66	15·8	13·12	22·21	11·43	1·12	..	·06

Gneiss.

Gneiss: its Origin.—That the materials of the mechanically aggregated gneiss rocks are derived from the disintegration of more ancient granite and other crystallised compounds, is an opinion which is strongly suggested by examining the composition of gneiss.

The component minerals of gneiss and granite are the same—quartz felspar, and mica. They are mixed with the like accidents and permutations, and occasional admixture of other minerals; and are subject in both rocks to the same extreme variation of size. But these rocks differ in the mode of arrangement among their constituent minerals.

The ingredients of granite are so connected together by contemporaneous or nearly contemporaneous crystallisation, that one mineral penetrates and is intimately united with another; and we are compelled to conclude that they were not accumulated in distinct crystals ready formed, but that the minerals never had a separate existence as solids until their different geometric forms were slowly developed by crystallisation.

Gneiss almost always suggests, by some degree of imperfection of the edges and angles of the quartz and felspar, and much more decidedly by the laminar arrangement of the mica and consequent minute foliation of the rock, that its materials, ready made and crystallised, were brought together and arranged by water. Gneiss in all its gradations, from a rock resembling granite to a fine-grained fissile mass hardly distinguishable from clay slate, may be compared with a series of sandstones, many of which are composed of granitic detritus, and strongly allied to it in structure, but not having undergone metamorphism, show unobliterated evidences that they were aggregated by water. Gneiss, however, is not always the crystallisation of materials in the layers in which they were aggregated, but more frequently a chemical integration of minerals under the solvent influence of water contained in the rock which was transformed; and this water first dissolved the constituents of the minerals, and then often became included in the minerals themselves.

In a great majority of instances, gneiss immediately rests upon granite; and we may suppose that the two rocks are effects of the actions of pressure and heat under different conditions.

Mineral Constituents of Gneiss.—Gneiss is essentially a mass of quartz and felspar, foliated with thin films of mica which are sometimes exposed by fracture. As in granite, the felspar is usually orthoclase, but oligoclase is sometimes associated with the orthoclase, though oligoclase is more frequent in hornblende gneiss and protogine gneiss; there are varieties of gneiss in which orthoclase is the only felspar. Occasionally albite is associated with orthoclase. Orthoclase varies in colour in gneiss quite as much as in granite, and is sometimes found in porphyritic crystals. The quartz occurs either in grains or small lenticular plates made up of many crystals united together. The

mica may be either potash mica or magnesia mica, and occasionally both micas are found in the same rock. Sometimes the mica surrounds the crystals of felspar, giving that mineral a lenticular form. Hornblende is an important constituent in many gneisses of the West of Scotland, and chlorite and talc are found in some gneisses of Scotland, so that gneiss has often been divided into mica gneiss, hornblende gneiss, and chlorite gneiss.

Texture of Gneiss.—Gneiss varies in texture with the condition of the mica. In the common type, mica is found in separate laminæ, dividing the felspar and quartz. But when the foliated texture is indistinct, owing to the imperfect continuity of the mica films, the rock is termed granitic gneiss, and makes a transition to granite. On the other hand, the mica may be so abundant as to isolate the quartz and felspar in lenticular masses; and in section this condition gives a delicate veined aspect to the rock. Sometimes the mica shows parallelism, giving the foliæ of the rock as regular an aspect as exogenous growth in wood; and this condition further developed imparts a platy cleavage to the gneiss.

Though the disintegrated materials of granite sometimes compose the substance of gneiss, fragments of granite are most rarely discovered in it.[1] But while gneiss may sometimes be a product of denudation of granite subsequently metamorphosed, more frequently the gneiss is simultaneously formed; and granite is only the same rock material more irregularly crystallised.

Transition from Gneiss to Granite.—Professor Heddle recognises three varieties in this form of metamorphism. First, there is a gradual increase of granitic texture over the gneissic texture. This condition may be seen on the north-east of the hill of Scoltie, near Banchory, where granitic veins of segregation or veinstones appear in the gneiss, while a couple of miles north the gneiss is becoming granite, owing to a steady increase in the number of the granitic bands. The veins themselves become larger, are free from foliated texture, and the granite was a fine grain. Further on towards the hill of Fare the granite bands progressively augment, and the gneissic bands are seen dwindling away.

The second form of granitic metamorphism is abrupt, and is well seen in the quarries of Tillyfourie, where the gneiss is highly contorted, broadly banded, and passes suddenly into granite without any trace of intermediate mineral condition. Yet there is no space where the one can be said to be in contact with the other. The openings between the foliæ of the gneiss cease to exist along a wavy course, the only sign of change being that sometimes the dark mica of the granite has its plates parallel to the line of the transition near to the unaltered rock.

Thirdly, there is metamorphism by a gradual fading of granite into

[1] MacCulloch says that in certain varieties of *mica schist* fragments of granite, of quartz rock, and of limestone are embedded in it. John Phillips suggests that he may not always have been careful to avoid admitting conglomerates among mica schist and gneiss.

gneiss. This is seen in quarries of the stony hill of Nigg; the gneiss is fine grained, plicated, and darkly striped; its layers gradually pass into granular dark grey granite. Fragments of gneiss are often found in the Aberdeen granite, and Heddle regards the kidney-shaped inclusions, rich in black mica, as portions of gneiss.[1]

Bedding of Gneiss.—Beds of gneiss are of various thicknesses, and the laminæ of which they consist are subject to such extraordinary curvatures, that it is often difficult to trace them.

Where gneiss alternates with other rocks, such as hornblende slate, quartz rock, limestone, or mica slate, the stratification is rendered very evident, but otherwise the beds are less regular, and often discontinuous.

The contortions of the laminæ of gneiss are most numerous and surprising where, as frequently happens, veins of granite, quartz, or felstone divide the gneiss. These veins cross the laminæ at various angles, and generally cause some peculiar twists along their sides; veins not infrequently insinuate themselves between the laminæ, and in this case, when thick and extensive, may be mistaken for alternating strata. Some cases of supposed alternation between gneiss and granite may be thus explained, and in other cases the rock called granite may be really a coarsely-granular gneiss.

Minerals in Gneiss.—Gneiss being one of the most widely-distributed foliated rocks, is a rich repository of minerals, both in the Old World and America. Garnets frequently, zircon, beryl, disthene, epidote, tourmaline, rutile, oxide of tin, oxide of iron, sulphide of molybdena, more rarely, are disseminated in its laminæ. The veins of quartz, calcareous spar, carbonate of iron, and sulphate of baryta, which divide it, contain the sulphides of lead, copper, and zinc, native silver, tin, &c., in Sweden, Germany, and Brazil; and many other minerals occur in the calcareous strata which alternate with or are enveloped by layers of gneiss. We can only suppose that the metallic substances diffused in the sea were extracted by organisms, or precipitated with the sediments, and that the minute and diffused particles became collected by solvent water under the influence of metamorphism.

Rocks Associated with Gneiss.—Gneiss alternates with granite in the Riesengebirge and in Quito, and in some cases graduates into the character of granite, as on the southern declivity of the Titlis and Jungfrau (the age of this gneiss, however, may be more recent); more frequently it exchanges beds with mica schist, hornblende schist, and granular limestone and clay slate. These rocks are sometimes in such small quantity as merely to mark lines of division in the mass of gneiss, but at other times they swell out to great thickness.

The limestone beds in particular are remarkably local and irregular in their occurrence, and instead of extending, like the more recent calcareous strata, through large tracts of country, appear in the form of large lenticular masses, enveloped on every side by the predominant

[1] Heddle, Trans. Roy. Soc. Edin., vol. xxix. p. 6; see however *supra*, p. 218 and p. 259.

rocks of gneiss. The term *subordinate*, on a great scale, is not improperly applied to these lenticular masses, though in local geology their occasional great extent and comparative regularity may entitle them to be classed under an independent title.

By the substitution of hornblende for mica, gneiss gradually changes to hornblende schist; the loss of its felspar approximates it to mica schist, the diminution of its mica produces a resemblance to quartz rock. A finely granular slate, with more evidence than usually appears of watery friction among the particles, almost makes a transition from gneiss to sandstone, as at Dalnacardoch. A more minute admixture of its ingredients, with a predominance of chlorite, gives it the aspect of argillaceous slate. These gradations are observed most frequently at the junctions and alternations of the several rocks.

Gneiss forms Intrusive Veins.—Von Cotta remarks that it was formerly believed that all gneiss is of metamorphic origin, but it has been established that many kinds of gneiss are eruptive. In the mining districts of the Erzgebirge there is a red gneiss containing 75 per cent. of silica, and a grey gneiss containing 65 per cent. of silica; and this red gneiss or gneissite is said sometimes to form dykes and veins in the common grey gneiss.

Grey Gneiss Associated with Mineral Veins.—The grey gneiss is more frequently associated with metalliferous veins rich in silver, and this relation has been attributed to the influence of the iron yielded in greater quantity by the decomposition of the mica in the grey gneiss.

Geological Age of Gneiss.—Gneiss commonly occurs beneath the sedimentary rocks. It has hence often been regarded as the oldest rock, and there is a disposition among geologists to refer any gneiss beneath primary rocks to the most ancient or Archæan period of Dana. But since slates occur of all geological ages, and granite originated in every period of geological time, we are compelled to believe that schists must have similar differences in antiquity. But gneiss of these several periods has not yet been determined, because it is almost impossible to fix the age of the base of the gneiss, though the age of the stratified rock above usually offers no difficulty. On the Continent there has been an attempt to separate an older and a younger gneiss, the older rock being beneath the strata, and the younger gneiss resting upon them. But such an anomalous succession suggests the probability of its being due to some grand inversion of the country; though, since metamorphism may be of any geological age, there is nothing impossible in gneiss of any age resting upon any strata.

Fundamental Gneiss.—Among the Continental localities for gneiss, Zirkel mentions the Saxon Erzgebirge. This rock near Freiberg has been divided into an older grey gneiss free from inclusions, and a younger gneiss, grey or red, which includes fragments of the older gneiss and various slates. Much of Bohemia and Moravia is formed of the younger gneiss. Similar rocks are seen in the Sudetic mountains, the Eulengebirge, and Riesengebirge, and

the west of the Schwarzwald and Böhmerwald. Gneiss is an important rock in Central France, and it forms much of Scandinavia and Finland. With these rocks are grouped the gneiss which skirts the coast of Brazil, and that which constitutes the Laurentian rocks of Canada.

The gneissose rocks of the Outer Hebrides and West Coast of Scotland were first distinguished by Sir R. I. Murchison as "fundamental gneiss;" and he subsequently endeavoured to identify the rock with the Labrador series of Canada. This gneiss extends from Cape Wrath to Loch Broom, Loch Maree, and Loch Torridon; and here, as in the long island of the Hebrides, it is a mass of granitoid gneiss, in which hornblende and quartz are much more important than felspar and mica. Its strike is from north-west to south-east.

Gneiss which Rests upon Stratified Rocks.—North-east of Chemnitz and west of Freiberg three large masses of gneiss, many thousand feet thick, extend in a line. They rest upon Silurian slaty rocks, and are covered by carboniferous conglomerate. Gneiss extends about Munchberg, north-west of the Fichtelgebirge, and fills an elliptical basin of eight square miles in the newer clay slate. The gneiss appears to rest unconformably on the rocks beneath. This condition is attributed by Gümbel to inversion, but is sometimes supposed to indicate a younger gneiss. In West Finnmark a thick gneiss rests upon clay slate, limestone, and mica slate. In Central Norway crystalline slates rest upon Silurian strata; and David Forbes described sections above Christiansand in which bands of granite about ten feet thick alternating with limestone are interstratified in gneiss. All these rocks are mixed in extraordinary confusion on the Torresdale river, where foliated gneiss passes into granitic gneiss, and both alternate irregularly with granite and limestone.

In the Alps, about the Col de Geant, near Mont Blanc, by the Grimsel and St. Gothard, for example, gneiss is found folded between beds of limestone which cannot be older than the Lias. Hence the gneiss must have originated after the Lias was formed.

Mica Schist.

Its Origin.—Mica schist, like gneiss, appears sometimes to have derived its ingredients from the destruction of granitic rocks, though it contains but little felspar. We may conjecture that the felspar was decomposed during the disintegration of granite, and mostly carried away, leaving the quartz and the mica to be arranged by the water in the alternate layers which render this rock so remarkable. Such ideas are readily suggested by the structure of the Millstone grit and Carboniferous sandstones of the North of England; though its association with granite favours the belief that it originated under similar conditions.

The foliation of mica schist is subject to much unevenness in

consequence of the irregular size and arrangement of the pieces of quartz; and the undulations thus occasioned on the micaceous surfaces are often further modified by interspersed garnets, the growth of which appears to have pushed aside the other ingredients. Besides this minute inequality, the laminæ of mica slate are liable to the same contortions and curvatures as those of gneiss;

Fig. 73.—Mica Schist at Loch Lomond.

the same difficulty often occurs in tracing its beds; similar and very numerous veins of quartz traverse and mingle with its layers; and when in contact with granite it is locally penetrated by similar granite veins. Small cavities lined with crystals appear among the most contorted parts.

Mineral Constituents of Mica Schist.—The kind of mica in mica schist varies with the locality. In the St. Gothard the soda mica Paragonite is found. In some localities the yellowish-white potash mica is rich in water, and forms the species Damourite. The colours of the mica vary, but dark magnesia mica is most common. This mineral determines the colour of the schist, which is grey, or greenish-grey, or yellow-grey, or may be brownish black.

The quartz occurs in grains, scattered between parallel layers of mica scales. As the quantity of quartz increases, the grains become large, flattened lenticular plates, among which films of mica are diffused. Occasionally the quartz becomes so abundant as to be only separated into layers by thin films of finely-divided mica, and such varieties make a transition to quartzite. The varieties which are poorest in quartz always have small grains of quartz enveloped in the laminæ of mica. The varieties of texture are similar to those of gneiss; but the crumpled wavy structure is one of its most typical modifications.

Ripple-Drift in Mica Schist.—Dr. Sorby has described the structure of mica schist, in which he recognises the "ripple-drift" seen in sandstones. This drift structure is by no means rare in the mica schist of the Highlands of Scotland. It may be well studied between Aberdeen and Stonehaven, and between Arrochar and Tarbat. In many specimens of typical mica schist the original grains of sand may be recognised under the microscope, because the original quartz is full of fluid cavities, and is surrounded by the clear quartz of the schist, which may similarly enclose grains of felspar sand.[1]

Flexures of Mica Schist.—The accompanying sketches (figs. 73, 75) were taken from the mica schist near the anticlinal axis of these beds which crosses the upper part of Loch Lomond. On a *great scale*, the laminations of gneiss and mica schist are suffi-

[1] Q. J. G. S., vol. xix. p. 401.

ciently parallel to give the idea of disturbed surfaces of deposition; on a *small scale*, by close examination, innumerable centres of local forces, producing minute, recurring, and anastomosing curvatures, appear.

Fig. 74.

These *minute flexures* are due, not so much to general or external pressure of the whole mass, as to the mechanical displacements effected in the mass by the generation of new minerals, as garnet, or the aggregation of others, as quartz, or felspar, or both. Thus the mica and chlorite which generally meet the surfaces of lamination appear to have been shouldered about without being fused, twisted in their structural planes, and subject to that curious minute folding which is often observed as one of the effects of cleavage structure in delicate and pliable shells, in slates, for which the term "creep" was introduced by Professor John Phillips (fig. 74).

Accessory Minerals in Mica Schist.—Various minerals are disseminated through it, as garnet, which may be two inches in diameter or almost invisible. It is common in the Alps, abundant in Bohemia, rare in the Thuringerwald, and less rare in Scotland and Ireland. Emerald, beryl, disthene, tourmaline, felspar, epidote, hornblende, graphite, staurolite, chlorite, talc, fluor spar, baryta, are sometimes abundant. The accessory minerals give names to many local varieties of mica schist, such as garnet mica schist, chlorite mica schist, tourmaline mica schist, hornblende mica schist, &c.; and sometimes the accessory becomes the typical or dominant mineral. Molybdena, rutile, oxide of tin, wolfram, oxide of iron, grey cobalt, native gold occur. Its metallic veins are of the same nature as those in gneiss.

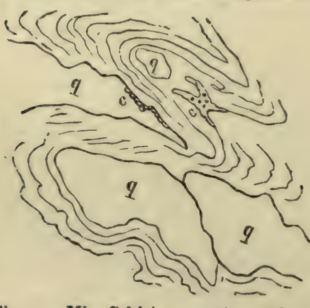


Fig. 75.—Mica Schist. *q* quartz, *c* chlorite.

Physical Relations of Mica Schist.—Mica schist alternates in the same way with quartz rock, hornblende schist, and the older slates, and encloses similar deposits of limestone and dolomite. It seems, therefore, almost superfluous to say that the line of rigid distinction between mica schist and gneiss cannot be drawn in the field. On a great scale the two rocks retain their typical characters over large tracts of country, and their distribution is hence essentially the same.

Quartz Rock.

Quartz rock, in the greater number of instances, especially when occurring in veins, seems more recent than mica schist and gneiss, though by easy changes in composition it becomes nearly identical with them. The internal evidence of texture seems to decide the question of the origin of quartz rock, and to prove that, however altered by subsequent

metamorphic action, it was originally a mechanical deposit. The degree of compactness which it exhibits varies extremely, in some cases approaching the loose granular character of sandstone,[1] in other cases it has the density of the quartz of veins. In this latter case it seems that the mass is composed of fragments so firmly united as to suggest the idea of their having been soldered together by fusion or cementation by infiltration, since their deposition from water. Perhaps, also, in some cases, what has been considered as quartz rock may be really an expanded quartz vein.[1]

Minerals in Quartzite.—In South America quartzite is the repository of many rich ores and metals. Native gold is found in Brazil in a stratified quartz rock, and micaceous iron ore appears to be intimately related to quartz rock. The "flexible sandstone" of the same country is a granular rock with drusy cavities containing topaz and amethyst.

Crystalline Limestone.

Its Origin.—Crystalline limestone is in general stratified; it frequently alternates with gneiss and mica schist, and sometimes retains argillaceous partings; it was therefore a water-formed deposit. Its state of granular or saccharoid crystallisation is due to changes developed since its deposition, and partly occasioned by the action of heat on contained water: this change is more obvious in the deeper-seated than in the newer calcareous deposits.

The beds of crystalline limestone, whether distinctly stratified or not, are in general detached and limited, and so entirely enveloped in gneiss and mica slate, as to form but subordinate members of those widespread rocks. This fact is in harmony with the occurrence of thin and imperfect limestone bands among the Devonian slates of West Somerset and North Devon, and appears to indicate that in the earlier periods of British geological time the precipitation of calcareous matter was of a more local and limited nature than those depositions which produced the widespread strata of Carboniferous Limestone, Lias, Oolite, and Chalk.

However we may seek to explain it, the fact is undoubted, that during the deposition of the rocks which were afterwards converted into gneiss and mica slate, a large quantity of calcareous sediment was deposited, not in one uniformly extended stratum, but at scattered points and in unequal quantity. And this irregularity of deposition continues to be observed in an inferior degree in the limestones of Cambrian and Silurian age, which are often lenticular; but above this horizon the calcareous strata become more abundant, regular, and extensive.

Minerals in Crystalline Limestone.—Though crystalline lime-

[1] Some of the quartz rocks of Scotland and Anglesea have a conglomeritic character. In Garveloch, Von Dechen noticed rounded masses of granite, quartz, and corneous limestone embedded in a basis of clay slate, passing to quartz or mica schist. Mr. Sharpe cautions us that some of the quartz rocks of MacCulloch are of later date (Phil. Trans. 1851).

stone is a simple rock, its aspect admits of many variations from unequal admixture with other mineral substances. Of these, the most frequent are mica, talc, and steatite, the latter of which often communicates a green or mottled colour to the whole rock. Crystals of augite occur in the Island of Tiree, garnets and felspar crystals in the Col de Bonhomme, and tremolite occurs in it in some places. Argillaceous slate lies upon its laminæ. It sometimes assumes a brecciated character, as if composed of limestone fragments, and more rarely it contains fragments of gneiss and mica slatc.

It is used for statuary carving and architectural decoration; contains a great variety of minerals; and locally is traversed by veins of quartz, felspar, and granite, and by veins of cobalt, galena, and iron.

Contains no Organic Remains.—The limestone associated with gneiss and mica slate is usually destitute of organic remains. Gneiss and mica schist were therefore formerly classed as *hypozoic*, or beneath the strata which contain evidences of *palæozoic* life. It has been said that if we suppose the crystalline limestones which are devoid of organic remains to have derived their peculiar texture from changes subsequent to their deposition, developed under the influence of water, subterranean pressure, and heat, it is probable that the absence of organic remains may be a consequence of this change.

Summary.—To conclude this discussion, we may collect in a small compass the possible speculations of the origin of the gneiss and mica schist.

Gneissic foliation is often the original, or the remains of the original lamination, imparted to the mass by the successive accumulation of its particles under water, and altered by subsequent action of water, pressure, and heat. These circumstances are sufficient in some cases to modify the internal texture, and almost to obliterate the structure, and thus to reconvert the sandstone into gneiss and the gneiss into granite; in other cases the grains of quartz, felspar, and mica are united together, and new minerals of easier fusion like garnet are generated; and in other cases the sandstone acquires a superior degree of coherence, and becomes quartzite. This view reconciles the diversity of the gneissic and schistose beds with probable differences of mechanical origin of their materials and degrees of applied heat; and takes account of the general truth that the foliation of the whole gneissose and micaceous series is parallel to the great axes of earth-movement. The excessive abundance of minute flexures, the occurrence of many cavities, and the frequency of intrusive quartz veins, are observed on and near to the summits of the arches of the laminæ.

CHAPTER XXI.

DISTRIBUTION OF GNEISS AND MICA SCHIST.

In England, &c.—The extent of country occupied by old gneiss and mica schist with their associated rocks is enormous, and there are few districts of large area where granite appears without being surrounded by foliated rocks. The order of their succession and their relative thickness are very uncertain. In some districts gneiss, in others mica slate, in others quartz rock, is the only rock seen, and that is immediately succeeded by clay slates. There are even cases where the whole metamorphic system is wanting, and large areas of granite are immediately invested by clay slates and limestones containing organic remains. In England, for example, gneiss and mica schist, crystalline limestone and quartz rocks are almost unknown; but in Ireland, and especially in Scotland, they are abundant, and include many gradations of mineral composition, such as chlorite slate, talc slate, hornblende slate, &c. The general order of succession among the older primary strata in Scotland may be represented in a diagram as in fig. 76, but it must be remembered that all the terms of the series are seldom co-existent in the same section.

Fig. 76.

In Cornwall and Wales the granitic rocks are almost universally succeeded by modifications of clay slate, Anglesea alone exhibiting a quartzo-micaceous group below all the Cambrian slates. In Cumberland the granite of the river Caldew is indeed covered by rocks having the character of gneiss, mica schist, dark hornblende slate (provincially called whintin), and chiastolite slate, but their area and thickness are inconsiderable, and the latter rock soon changes to clay slate. At a place called Martindale, at the eastern foot of Caldbeck Fells, is a fine-grained variety of gneiss in very thin laminæ. Granite veins are rarely known to divide any of the rocks of this region, except on a small scale between Skiddaw

and Saddleback. Gneiss occurs, sometimes exchanging its mica for hornblende, on the east flanks of the southern parts of the Malvern Hills, where it is much intermixed with dolerite. It may be regarded as older than the Cambrian rocks.

Schists of the Lizard.—The serpentine of the Lizard district, which has an intrusive aspect, seems to rise as a boss within a girdle of schists. These schists, which form a single natural group, are nevertheless divisible into three series, which Professor Bonney distinguishes as micaceous, hornblendic, and granulitic. The lowest series consists of compact dull green schists and brown mica schists. The middle group is formed of black hornblendic schists, which are shining, and banded with felspar or epidote. The uppermost series is formed by pinkish-grey rock, composed chiefly of quartz and felspar, but banded with micaceous layers and seams of dark hornblende.

The lowest group is well shown on the southern coast of the Lizard, especially about the point called the Quadrant; and in the next cove there is a faulted junction between the micaceous series and the hornblendic series. The hornblendic group is well shown in Houzel Bay; and at Hot Point the rocks show lenticular bedding, with remarkable instances of false bedding and indications of ripple-drift. These hornblendic schists are frequently rich in epidote, and sometimes have a granitoid character. At the bay under the Balk quarry, where the first intrusion of serpentine is seen, the commencement of the granulitic series is found. These rocks consist of distinctly stratified beds of massive quartz, alternating with schistose bands. The quartzite is sometimes felspathic, and occasionally contains a little mica or hornblende, but the darker schistose layers are rich in these minerals. Lenticular bedding and current bedding are rare in this group. The hornblende schists are well developed on various parts of the coast, as in Polurrian Cove, and on Pradanack Point, where the schists become very massive, and in hand specimens resemble a diorite. Professor Bonney calculates the maximum thickness of the whole series at about 3300 feet, of which rather less than three-fourths would belong to the hornblendic group, and about 300 feet to the granulitic group. These schists have lost their original structure, and many have become highly crystalline, but the current-bedding appears to be preserved, especially at Hot Point, although the constituents of the rock have undergone a crystalline change. It is suggested that the metamorphic agency softened the whole rock mass, so that the materials crystallised much as they would have done had the rock material been igneous; and in places the unaltered or undigested rock remains, surrounded by crystalline minerals which form granitoid bands. Professor Bonney thinks that such hornblendic schists may originally have been basaltic tuffs. Such an origin would explain the close correspondence between some of the altered rock and diorite, which furnishes evidence of unusual interest concerning the transition between the water-formed and fire-formed rocks. The progress of metamorphism may have been extremely slow, for the change consisted in the replacement of the materials of the rock under conditions of pressure and crumpling such

as earth-movements might produce. The age of these schists is uncertain, but they present a close resemblance to the micaceous and chloritic schists of Anglesea and Holyhead, and they have similarly been grouped with the Archæan series.[1]

Schists of South Devon.—The rocks of South Devon between Start Point and Bolt Tail are highly metamorphosed. They consist to a large extent of mica schist, though in many places this rock gives place to chloritic schist, as at Prawle Point and in Bolt Tail itself, and on the east side of Salcombe estuary. This region has always appeared interesting because Sir Henry De la Beche was inclined to regard it as indicating progressive metamorphic action, which increased in intensity southward, while Sedgwick and Murchison inclined to the belief that the southern schists show no transition to the northern slates. Their views have been confirmed by Professor Bonney, who finds that there is a passage from slates and phyllites to rocks with incipient metamorphism into schists, which is too rapid to indicate transition. This author observes concerning the mica schists that in some cases the structure of the crystalline constituents indicates that folding has been the first stage in the process of metamorphism, and that the chemical or mineral change has been subsequent to the mechanical one. In other cases the folding and crystalline changes appear to have been produced together, while in a third case the rock was crystalline before it was folded. Professor Bonney arrives at the conclusion that the metamorphism was long anterior in date to the great lateral compression which has corrugated the rocks. Dr. Holl regarded the slates at Tor Cross as newer than the Plymouth Limestone, but Professor Bonney thinks that the Cornish metamorphic rocks suggest that these may be a prolongation of the schists of the Lizard, which may have included the gneiss of the Eddystone, and that they too date back to the Archæan period.[2]

Metamorphic Rocks of Anglesea.—Anglesea exhibits schists in grand development. North of the Holyhead Road they are green and purple, and often micaceous, and lie in wavy lamination. North of Church Bay they are a white or yellow felspathic schist; and between Carmel's Point and Church Bay gneiss is well developed, and the bedding has so entirely disappeared that the rocks have the aspect of igneous masses. In this part of Anglesea the bedding and foliation cross each other. Holyhead Island is formed of gnarled schists, in which stratification, foliation, and cleavage are frequently indistinguishable. Nowhere are the strata more violently contorted than in the cliffs and islets round Holyhead. The eastern half of Holyhead is described by Sir Andrew Ramsay as a kind of quartz rock. Professor T. M'Hughes indicates four great masses of gnarled schists, the Holyhead mass, the Amlwch mass, the Llangefui mass, and the Menai mass.[3]

Foliation in the Volcanic Series of St. Davids.—Professor A. Geikie remarks that a fine foliation, arising from the development of

[1] Bonney, Q. J. G. S., vol. xxxix. p. 1. [2] Q. J. G. S., vol. xl. p. 1.
[3] Q. J. G. S., vol. xxxvi.

micaceous minerals along the planes of stratification, has been extensively developed in the volcanic group of St. Davids (as we have observed in ashes in the Eifel) and in the overlying sedimentary rocks. It has affected many fine tuffs, the paste of some coarse tuffs, and some shales. Where it occurs the rock is usually pale apple green to pearl grey, sometimes pink, with a lustre like silk and a soapy surface. Under the microscope the base of the schist is a felted aggregate of minute scales of nearly colourless mica. Chlorite and some other minerals occur with it. The schists which are interstratified with the sandstones and shales above the conglomerate present almost identical characters.[1]

Gneiss in Scotland.—Gneiss is abundant in Scotland, particularly in the northern and western parts, and being exceedingly variable in composition, is very often indistinguishable from mica schist, under which head M. Boué preferred to class many of its varieties.

Gneiss constitutes almost the whole mass of Iona, Tiree, Coll, Rona, and the Long Island of the Hebrides, and enters largely into the composition of the Shetland Isles, which are in some measure to be viewed as a prolongation of the Hebridean group, just as the Orkneys appear to be an extension of the eastern rocks of Caithness. Housa, Burra, Whalsay, Out Skerries, and Yell, and the western parts of Fetlar and Unst, and part of the mainland of Shetland, are gneiss. The remainder of the mainland is principally mica slate, and the two rocks are partially separated from each other by an interrupted deposit of limestone. The gneiss is often porphyritic, as in Unst; at Hagrasattervoe[2] it appears to contain masses of granite, as well as to be traversed by veins of syenite and talcose granite. Kaolin is derived from it in the Mainland and in Fetlar. Gneiss exists in the Orkneys, around the granite of Stromness.[3]

In the Hebrides this rock changes often from the typical mixture of quartz, felspar, and mica, by the substitution of talcose minerals and hornblende for mica, by the omission of the quartz, and by the interlamination of argillaceous schist. Some varieties are extremely slaty, and suffer rapid decomposition; others approach nearer to granite, and present rude and naked surfaces and precipitous faces, with few brooks and little alluvium. The direction of the strike of the strata in the Hebrides is north-west and south-east, but the inclination of the beds is obscured by frequent contortions. These are most frequent in the vicinity of the granitic veins which divide all the gneiss rocks, except those which are associated with clay slate. The drawing which MacCulloch gave of the contorted laminæ of gneiss and hornblende slate in connection with ramifying granite veins near Cape Wrath seems to justify his views, for the laminæ of gneiss are often peculiarly bent or apparently dislocated along the line of the veins, and sometimes masses of this rock are curiously enveloped in their substance.

[1] A. Geikie, Q. J. G. S., vol. xxxix. p. 310. Where also see Prof. Geikie's account of the metamorphism produced by contact of granite with stratified rocks.
[2] Hibbert, Edin. Phil. Jour., vol. ii.
[3] Boué, "Géologie de l'Ecosse."

Rocks in West of Scotland.—The veins are not often filled with granite of the ordinary kind, but with a compound rock, in which felspar highly predominates, so as to form in several places (Harris, South Uist, Rona, and Coll) a real graphic granite, which in Coll contains garnets. Veins of quartz, occasionally metalliferous, likewise traverse the gneiss of Coll and Tiree. Garnet, rose quartz, zircon, hornblende, epidote, fluor spar, iron pyrites, and sulphide of molybdena, occur in the gneiss.

In Rona, Coll, and Tiree, mica schist alternates universally with the gneiss. Gneiss occurs in many places, as round the granitic mountains of Braemar and Lachin y gair, at Kincardine, in Ross-shire, and other points in the extreme North of Scotland; but the most abundant and interesting mass adjoins the granite of Strontian. It forms the beautiful and picturesque region around Loch Sunart, which strongly resembles the Trossachs of Loch Katrine, being equally rich in wood and remarkable for intricate confusion of rugged surface. The curvature to which its laminæ are here subject are very numerous and extraordinary; veins of quartz, felspar, and granite are extremely common, garnets abound in it at certain points, and in the metalliferous veins are carbonate of strontian, harmotome, and calcareous spar. On the eastern side it is bounded by porphyritic masses, but in other directions appears to be overlaid by mica schist, to which its composition approximates.

Mica Schist in the Highlands.—But the principal part of the Highlands is occupied by mica schist, whose layers range with more or less regularity north-east and south-west, notwithstanding the interruption to their continuity by the unstratified rocks of the Braemar mountains and the groups of Ben Cruachan and Ben Nevis.

The south-eastern limit of this vast crystalline area is the line of the foot of the Grampians from the Firth of Clyde to Stonehaven. Deposits of red sandstone, lias, and a coal-bearing part of the oolites border the eastern coast from the river Spey to Duncansby Head, and extend through the Orkneys. Rocks of igneous origin associated with schistose rocks mostly occupy the base of the volcanic regions of St. Kilda, Skye, Rum, Eigg, Mull, parts of Ardnamurchan and Morven. Within these limits, and with the exception of irregular masses of igneous rocks and of gneiss, the whole of the vast space belongs to the mica slate series, with its included quartz rocks, limestones, serpentines, potstones, associated hornblende slates, and talcose slates, and overlying clay slates.

Metamorphic Rocks on the Southern Slope of the Grampians.—Professor Nicol remarks that the clay slate extends along the southern flank of the Grampians from Arran to Stonehaven. In Arran it is parted from the mica slate by granite. In Bute the clay slate rests on mica slate, and both dip south-east. This dip extends along the Firth of Clyde, and at Gareloch the junction of the mica slate and clay slate is well seen. The mica slate runs up Loch Long, and is so twisted and contorted that the dip is undeterminable. The rock is a lustrous slate, which towards the

Gareloch becomes less crystalline and more sandy, and disappears beneath the clay slate near Roseneath. The lower clay slates are micaceous, deep blue or purple; the upper are light blue or green and silvery. This is the normal order of the beds on the south border of the Western Grampians.

Structure of Ben Lomond.—Ben Lomond consists at the north end of mica slate, often quartzose, greatly contorted, but with the dip becoming more regular near Rowardennan on Loch Lomond. The mica slate passes sometimes into grey talc slate when the beds become intersected by a parallel vein of fine-grained syenite. Farther on, at Sallachie, the clay slate rests conformably on the mica slate, and according to Professor Nicol the bedding and cleavage coincide.

Slate Rocks of the Trossachs.—To the north of Callander the mica slate and clay slate are well exposed in the Pass of Leny and on the banks of Loch Lubnaig. In the Pass of Leny the lowest beds of clay slate show distinct grains of quartz of sedimentary origin. Then succeeds a great mass of chlorite slate full of reticulate quartz veins associated with foliated rocks consisting of quartz and felspar, and these rocks pass into blue talc slates, which are succeeded by mica slates dipping to the north at an angle of 73 degrees. Ben Ledi is a great mountain on the west of Loch Lubnaig, which consists almost entirely of mica slate greatly contorted. Near Strathearn and Comrie the clay slate is seen in contact with the syenite of Ben Chonzie. The slates show distinct foliation. The syenite has the hornblende more or less replaced by mica, and has the felspar abundant. It sends veins into the slate without producing much alteration. But as the slate rocks approach the syenite they become harder and more crystalline. Then lenticular masses of red felspar and quartz become mixed with the blue slate till the whole rock is converted into a fine-grained gneiss.

Mica Slate of Loch Earn.—Mica slate predominates along the north bank of Loch Earn, where it is greatly contorted, but with a general dip to the north-east; and Professor Nicol suggests that it here forms an anticlinal axis, which probably continues the contorted beds of Loch Long, Loch Lomond, and Loch Lubnaig.

Central Gneiss and Quartzite.—The gneiss of the Black Mount and Breadalbane Highlands, according to Professor Nicol, forms a synclinal trough and rests on both sides on mica slate. Near Killin at the head of Loch Tay the mica slate is mixed with hornblende slate and limestone. Round Tyndrum, mica slate is intermixed with beds of quartzite, with a varying dip to the south-east or north-west. At Urchay Bridge gneiss rests on mica slate on both sides of the valley. Beyond Urchay the gneiss continues by Inveroran and King's House to the top of Glencoe. This idea of the gneiss being the newer formation was opposed to the views of Murchison and Geikie. High up the pass of Glen Shee towards Braemar are certain limestones overlain by gneiss, which passes up into quartzite and forms the higher parts of these mountains. From Ben Turk Bridge, where there is a grey micaceous limestone dipping south-east, the valley

consists of gneiss with veins of granite. Professor Nicol remarks that the whole series seems to be conformable, and as though the gneiss were the more metamorphosed lower portion, and the quartzite the less metamorphic higher portion of one formation, which rests on the granite of Ben Macdhui and the Cairngorm mountains, without evidence of disturbance at the junction.

Gneiss of the North-West Highlands of Scotland.—The North-West Highlands of Scotland comprise a strip of about a hundred miles of country, running from N.N.E. to S.S.W. through the west of Sutherland and Ross. This region is formed almost entirely of gneiss and similar metamorphic rocks which were fully described by Sir R. I. Murchison and Professor Nicol. The succession of rocks from the west to the east is first fundamental gneiss, sometimes diversified by patches of igneous rocks; second, quartzite with limestone; and thirdly, the eastern gneiss. Whether this is a true succession has seemed doubtful since the discovery of fossils in the limestone at Durness. The succession has been accepted by experienced surveyors—Murchison, Ramsay, Geikie, and Harkness. It was contested by Nicol, who regarded the eastern gneiss as a repetition of the western gneiss consequent upon faulting, so that the occurrence of fossils of the genera, Maclurea, Murchisonia, and Orthoceras in the Durness limestone, and similar fossils in the limestones of Assynt and the quartzite of Loch Erriboll, would present no anomalies. The sections are such that considerable latitude in opinion may be allowed to all observers; for the contortions, the slips, the changes in mineral character, the occurrence of igneous rocks which break the succession, and such-like phenomena, impose caution. Dr. Hicks, who has examined the southern part of this country, accepts the view of the younger gneiss being a separate formation, and regards the older stratified rocks as resting unconformably on gneissic and pre-Cambrian rocks, which have a different strike; and with him the unconformity stands in place of the fault, while the western gneiss is made to reappear to the east.

Hebridean Gneiss.—Dr. Calloway has examined the sequence in Loch Broom, Assynt, and Loch Erriboll, and regards the eastern gneiss as newer than the western gneiss, but older than the Assynt series. The lower rocks of this region, called fundamental gneiss or western gneiss, are also termed the *Hebridean.*

The Hebridean gneiss, according to Heddle, is composed almost entirely of pink orthoclase, dark-green hornblende, small-flaked black mica, and quartz with a greasy lustre. The hornblende and mica are especially aggregated into broadly-banded stripes. At the south-west of Sutherland, at Loch Inver, and towards Loch Polly, the gneiss is greatly convoluted; its layers become smaller, and the banding is less prevalent. Where the rock is exposed to the sea, near Cape Wrath, the felspar bands weather out, leaving the hornblende standing isolated. At Cape Wrath the gneiss dips south-east; its prevalent strike is north-west to south-east; but in Sutherland its dip is south-west.

Caledonian Gneiss.—The eastern gneiss is termed the *Cale-*

donian. It includes in the Erriboll area a lower division, *the Arnaboll series*, well developed in Ben Arnaboll, which consists of grey granitoid felspathic gneiss, overlain by dark hornblendic gneiss and mica gneiss, which present a striped aspect. The upper part of the Caledonian consists of the ordinary flaggy gneisses, exposed on Loch Hope and Ben Hope. This *Hope series* preserves its character from Loch Erriboll to Loch Broom, and eastward to Lairg in Sutherland and Ben Wyvis in Ross. The upper gneiss is thin-bedded and highly quartzose, sometimes passing into quartzose schist, and sometimes into felspathic gneiss.

The Assynt Series.—A third group is the *Assynt series*, which now lies between the western and eastern gneiss. The rocks are comparatively unaltered. The quartzites contain annelid remains, and possibly plants. The lowest of these Assynt rocks are subdivided into the *Torridon sandstone* below and *Ben More grit* above. This grit, composed mainly of quartz and gneiss, has the fragments, sometimes several inches in diameter, embedded in a chloritic ground mass, and passes up into green grits and other fine sediments, sometimes sandstone, sometimes shale. The Torridon rocks appear to be about 300 feet thick, and though the bottom conglomerate covers miles of country, it is not more than 100 feet thick.[1]

Over the Torridon sandstone rocks are the *quartzites* and seamy quartzite with felspar grains, covered by the *Annelid-bearing quartzite*, or pipe rock, characterised by vertical burrows, which is seen between Loch Broom and Loch More, and on Loch Erriboll. These quartzites are about 300 feet thick.

Next succeed the brown flags, fine-grained sandy rocks, sometimes argillaceous, sometimes dolomitic, and these rocks graduate upward into the grit, which contains *Salterella Maccullochii.* Finally, the Assynt series includes the dolomite, which in its lower part is dark grey or black, and in its upper part nearly white. The dolomite is about 300 feet thick. The total thickness of the Assynt series is upwards of 1000 feet.

All these rocks have been greatly contorted, so that the Assynt series is doubled back upon itself all along Loch Erriboll in a compressed synclinal fold, which brings the quartzite over the dolomite; and there is an overthrow of the eastern gneiss or Caledonian formation upon the Assynt series, and sometimes the Caledonian is brought over the Assynt series by a reversed fault. On Loch Broom the Assynt series dips to the north-east, while the Caledonian series dips to the south-east. The Hebridean gneiss on Loch Broom is in contact with and slightly overlies every member of the Assynt series, and in its overthrow is sometimes accompanied by the Torridon sandstone. Dr. Calloway[2] regards the Caledonian gneiss as having been deposited unconformably upon the Hebridean rocks; but the relations of the two gneisses have yet to be demonstrated.

[1] See Drawings of Scenery in a paper by Heddle, in Journal Mineral Soc., 1880.

[2] Q. J. G. S., vol. xxxix. p. 355.

Scenery of Gneiss and Mica Schist.—The mountains of this system of rocks are formed into little groups separated by deep valleys and long lakes, while their summits rise often more than 3000 feet above the water. Their bases are usually and thickly covered with birch underwood, and sometimes with forests of oak. Scenes of a truly alpine character are very rare in Scotland, and perhaps nowhere occur except in the Cuchullin mountains of Skye and the granite peaks of Arran. The general outline of the mountains is pyramidal, but this form, elegant at a distance, is broken on a near survey by fantastic projections and bare cliffs and channels, which after storms are changed into a multitude of waterfalls. The mountains of quartzite and red sandstone rise abruptly from the great tableland of fundamental gneiss forming the lower hills on the West Coast of Scotland. The greater elevations are smooth rounded cones, spire-like peaks, or long serrated ridges, whose summits shine under the sun as though capped with snow, and they send down streams of fragments to the sea-lochs which wash their bases. The valleys which are destitute of lakes are usually wild and barren and covered with scattered rocks. Several of the most remarkable valleys in the Highlands follow the strike of the strata; as, for example, the extraordinary valley of lakes united by the Caledonian Canal, whose highest point is but 90 feet above the sea. The valley of the Spey, Glen Tilt, Loch Tay, Loch Long, Loch Fyne, Loch Awe, are other examples. The longitudinal valleys are remarkably narrow, as if mere slits in the country, while the numerous transverse valleys are in general more expanded.

One of the most interesting valleys in Scotland is Glen Roy, which branches off from Glen Spean in Lochaber. Narrow, parallel, contiguous terraces, perfectly level as seen from a distance, and continuous along the whole length of the glen, mark the higher part of its bordering slopes with singular and most surprising terrace deposits of boulder clay, often laminated and crumpled like the contorted drift of Norfolk, the effect of ancient local operations of ice and level water. It has sometimes been conjectured that these terraces are traces of the ancient margin of the sea, left uninjured during a subsequent elevation of the whole country, to the extent, perhaps, of 1500 feet. But the limitation of the terraces and the material of which they consist rather suggest that the valley was dammed with a barrier of ice which varied in level and held the waters in Glen Roy as a lake enclosed by glaciers.

As might be expected, the forms of the mountains, and especially the shape of their summits, are often characteristic of the kind of rock which constitutes them. Compare, for instance, the irregular head and broken slopes of the Cobbler and other mountains of mica slate, with the smoother sides and less angulated chloritic top of Ben Lomond, and the conical summits of quartz rock on Benan, Schehallion, and the Paps of Jura.

Neither are the features of the valleys and waterfalls independent of the nature of the rocks which they traverse. The unequal hardness of mica slate, in particular, is often evident in the rapid streams

by singular hollows and pits in their course and deep cavities under the cascades. A waterfall near Loch Earn Head exhibits this feature remarkably.

Examples of gneiss-like mica slate are found in Glen Tilt, Dalnacardoch, and many other points of the Blair Athole country, near Tyndrum, and sparingly around the granite mountains of Arran. In some specimens, as in Glen Roy, it appears composed of little else than mica folded and twisted round garnet crystals; in other cases, as by Ben Nevis, the garnets form almost distinct layers. In some cases (Glen Roy) the white mica and quartz form very smooth and attenuated laminæ, like those of cleavage; in others (Trossachs, Loch Earn) the quartz is in thick irregular plates, which mark one of the gradations to quartz rock.

Quartz Rock in Scotland.—Quartzite is exhibited in a sea cliff in the Whitten Head in Sutherland. Towards the sea it presents caverns and stacklike pillars, but its general form is rounded. The quartzite shows no trace of granular structure, and is free from veins. Quartzite is seen opposite to Kyle Akin, in Skye, almost vertical, highly tilted at Loch Kishhorn, and from Loch Broom to Loch Urigill there is continuous quartzite underlying the limestone. Quartz rocks and quartzose mica slates are seen in the North of Scotland, in Moidart, along Loch Shiel and Loch Eil, and the eastern side of Loch Linnhe. Above the granite of Glen Tilt quartz rocks abound in Ben y gloe, and in several mountains round the granite of Braemar, and may be well studied in the valley of the Bruar near Blair. They reappear in Mount Alexander, and on the sides of Loch Rannoch constitute the pyramidal summit of Schehallion, and on the borders of the granitic desert of Rannoch Heath are traversed by granitic and porphyritic veins. Quartz rock extends from Jura into Islay, and is found in Shetland.

Talcose Slates in Scotland.—Talcose and chloritic slates, holding an intermediate mineralogical character between clay slates and mica schists, occupy for the most part an intermediate geological position. They may be well studied on the banks of Loch Lomond and Loch Fyne, and several points on the south slope of the Grampians, where they are often rich in quartz, and remarkable for minute undulations and greater contortions. Chlorite slate is also found in the Long Island, and in Fetlar and Unst. The very common association of garnets with mica schist and gneiss is one of the effects of heat applied to those rocks since their deposition.

Hornblende Slate in Scotland.—Hornblende rocks, especially hornblende slate, occur in combination with mica slate. Hornblende slate is seen plentifully in Glen Tilt, and is much traversed by granite veins; on both sides of the Pass of Killiecrankie; south of Schehallion; north of Ben More; in the upper part of Loch Lomond, and under Ben Cruachan.

Serpentine in Scotland.—Serpentine, a rock whose geological relations are still imperfectly understood, occurs to a small extent in Scotland at many places, accompanied generally with chlorite or steatite,

and diallage rock. It is said to be most frequent among the upper beds of chlorite slate, though occurrences of serpentine in small quantities accompany the limestones of Iona, Glen Tilt, Harris, and Tiree. On the south side of the Grampians it occurs at Cortachie, on the North Esk, but through the North of Scotland its localities are more scattered. (Near Drimnadrochit, near Inverness.) The beautiful serpentine of Portsoy, said to be employed in some of the apartments at Versailles, forms "three vertical bands," one of them enclosed between hornblende rocks, another between hornblende rocks and crystalline limestone, and the third between quartzose talc slate and mica slate, which is covered by beds of limestone, hornblende slate, and talc slate, and the junction of all these rocks is softened by a mutual exchange of ingredients. In Scalpa, an irregular, highly-inclined bed of serpentine, one hundred yards thick, traverses the gneiss promontory of the lighthouse, and exhibits at its boundaries against the gneiss abundance of hornblende crystals, layers of talc slate, and a sublaminated structure. It contains steatite, asbestos, &c. The granite veins here observed traverse both the gneiss and its included serpentine, and in the latter rock chlorite is added to the ingredients of the vein.

Serpentine exists in Lewis, and occurs in Shetland in considerable abundance and beauty, both in the Mainland, in Fetlar, and at Brassa Sound in Unst, where it contains chromate of iron in sufficient abundance to be of considerable value in commerce.

Potstone is found in Glenelg, opposite to Skye, and in the serpentine of Scalpa. But the most remarkable rock of this kind is found at St. Catherine's, near Inveraray, on the opposite side of Loch Fyne. It is imperfectly slaty, and has been employed in the erection of the Duke of Argyle's mansion; other localities are the districts of Strathearn and Breadalbane.

Crystalline Limestone in Scotland.—The white crystalline marbles of Iona are found in rocks sometimes referred to mica slate, but considered by MacCulloch to be gneiss. The variously coloured marble of Tiree, with its embedded augite and hornblende, lies in alternating gneiss and mica slate. That of Glen Tilt, characterised by accompanying tremolite, lies in a quartzose mica slate associated with hornblende slate.

Boué, following up the notices of MacCulloch, traces the line of the Glen Tilt limestones to the east and to the west. In the western direction they proceed from Gow's Bridge, crossing the hills at Lude, and tending toward the south, pass through the Glen of Fincastle and across the valley of the Tummel. It is conjectured that limestone of the same range continues by Mount Alexander and the base of Schehallion, from whence it proceeds through Glen Lyon to the side of Loch Tay at the foot of Ben Lawers, reappears in Crien Larich, at the entry of Strathfillan to the west of East Tarbet, in Knapdale, and the head of the valley of Croe.

Eastward from Glen Tilt this limestone is traced in the course of the North Esk, and in the valley of the Dee, near Braemar, &c.

So extensive a range of limestone rocks in the direction of the strata of mica slate may be regarded as being thoroughout a nearly contemporaneous deposit. The limestones on Loch Laggan and Loch Eil in Inverness, and at numerous other points in Aberdeenshire, are referred by Boué to the same era.

The marbles of Sutherland were formerly worked in the Inchnadamph district, near Loch Awe; but they contain gritty particles which interfere with the polishing. Yellow and green serpentinous marbles occur with others of a chocolate-brown and light-red colour near Ledbeg, and a white marble runs from the south of the Ledbeg river through Loch Urigill towards Elphin. The Loch Ailsh marble forms two beds, a lower white saccharine marble being separated from the upper by a layer of argillaceous chert. The upper bed is less perfectly metamorphosed. This limestone contains about 5 per cent. of carbonate of magnesia, and over 4 per cent. of silica.

Second Range of Crystalline Limestone.—A second range of limestones, lying chiefly in argillaceous and chloritic mica slate, is considered to be of more recent origin. The points where it is seen are near Blairgowrie, at the foot of Ben Vorlich, on the north side of Loch Earn, Balquhidder, Inveraray, Knapdale, and Lorn; and the limestones of Balachulish, Cairndow, and Dalmally, as well as those which run from Boharm to Banff, are classed with this series.

Perhaps the relations between all these points may not have been correctly ascertained; but there seem excellent reasons for admitting that these calcareous rocks, like those which are more perfectly traced among the newer strata, were produced at a few definite periods, and not mere irregular formations having no relation to each other in respect of time. (See Geikie's Geological Map of Scotland.)

Garnets in Statuary Limestone.—Garnets are among the most characteristic products of metamorphism. As a rule, granules of quartz are scattered through the garnets, though in some granitic veins, as to the east of Portsoy, the quartz is arranged in the garnet crystals in a radiating manner. The colourless water garnet, a double silicate of lime and alumina, is remarkable for being free from iron. It is known from limestone quarries in the wood on Craig Mohr, opposite to Balmoral. The lime and alumina iron garnet known as grossular is a rare form found embedded in limestone in green crystals of the colour and size of peas. The lime iron and alumina garnet, termed cinnamon stone, is common in the limestone at Delnabo, Glengairn. The formation of these and the other minerals found in granular limestone is explained by pointing out that the limestone, in developing the crystalline structure of calcite, has extruded from itself the foreign substances it contained, much in the same way that sea water, when it freezes, separates the brine in small globules. Professor Heddle suggests that the high specific heat of limestone may have to be considered as a source of heat liberated when the rock passes from an amorphous to a crystalline condition, and cites many examples of the association of calcareous beds with argillaceous mica-schist, quartzite, and serpentine, especially in Banff, Aberdeen, and

the north of Perth, to show that those parts of the Upper Limestone beds which are associated with serpentine are richest in minerals, where both beds are included in gneiss; while the comparatively unplicated Lower Limestone in mica-schist is poor in minerals.[1] Limestones contain garnets as they approach granite.

The Isle of Man.—The granite of the central axis of the Isle of Man, seen at Barrule and North of Laxey, is succeeded by very little gneiss and mica slate, much Cambrian schists, from which the mica-schist and gneiss are metamorphosed, and quartz rock. The mica-slate is traversed by veins of quartz and schorl.[2]

North of Ireland.—The older strata of the North of Ireland may be considered as in part a prolongation of those of Scotland; thus the extensive spread of mica-slate in Londonderry and Donegal is a prolongation of the line of the chain of the Grampians, continued through Jura and Islay; and the clay slate ridges which border the Mourne mountains run in the direction of the Mull of Galloway and the clay slate chain of the South of Scotland, while between these two systems of slates, occupying a basin-shaped depression, are red sandstone, carboniferous limestone, and other strata of newer origin, corresponding to those which separate the analogous chains in Scotland.

The mica slate rocks are principally of the chloritic varieties without garnets, but contain hornblende. Laminated crystalline limestone of different colours, containing talc, quartz, hornblende, or pyrites, with veins of quartz, chlorite, and calcareous spar, occur in the mica slate in many parts of Antrim and Londonderry. Hornblende slate likewise forms distinct bands in the mica slate of this region, and felspar porphyry is interposed.[3]

South of Ireland.—In the south-eastern part of Ireland mica slate forms two ranges along the eastern and western boundaries of the granite, and wherever it occurs is in direct contact with the granite. On the eastern side of the granite it runs in a narrow course north-east and south-west, dipping deeply south-east, and consists of alternate layers of mica and quartz of extremely variable thickness. On the eastern brow of Rochetown Hill mica slate runs into a natural hollow of the granite, still retaining the north-east and south-west direction of its strata. On Maulin Hill it is singularly and fantastically contorted on a small scale. There is a prolongation of the body of mica slate at the head of Glenmacanass, gradually narrowed in its western progress, and constituting a wedge-like mass inserted into the body of the granite, and enclosing apparently a bed of granite six to ten yards in width, besides irregular masses of granite incorporated with the slate. In the district, greenish, sectile, chloritic slate lies embebbed in the mica slate, and is used for various purposes of architecture and ornamental carving.

In Glenmalur occurs a remarkable instance of decided alternation of granite and mica slate. In a space of 208 fathoms no less than

[1] Heddle, Trans. Roy. Soc. Scot., vol. xxviii. p. 311.
[2] Henslow, in Geol. Trans.; Cumming's "Isle of Man."
[3] Berger in Geol. Trans. and Mem. Geol. Surv. Ireland.

five distinct alternations of granitic beds, with as many layers of mica slate, are clearly traced, and several of these beds are made up of similar alternations of granite and mica slate or quartz and mica slate. The great mass of granite is below, and the great mass of mica slate above, constituting the hill called Lugduff. Granitite abounds in this slate.

Similar alternations occur in other neighbouring places, making a total thickness of one-third of a mile, and the whole system ranges north-east and south-west, and dips south-east. On the north-east they probably abut and terminate against the granite. The mica slate on the summit of Lugnaquilla is likewise interstratified with granite. Clay slate bounds it on the east, and at length coming into contact with the granite, cuts off its farther progress to the south.

On the western side of the granite the mica slate is still less extensive. It is found to enclose beds and elliptical masses of granite in Glenismaule; and it is mentioned that a granite vein, four to eight inches wide, ranging 25° north of west, cuts off the mass of alternating strata, without occasioning any displacement. In the same valley are two distinct beds of compact doleritic rock in the mica slate, one four feet wide, the other two feet. Andalusite abounds in the mica slate of this country; and dolerites alternate with it.

The frequency of the phenomenon of alternation between mica slate and granite is a feature in the geology of this part of Ireland long since discussed by Mr. Weaver.[1]

In Brittany.—The tract of old rocks in the north-western part of France is one of the most extensive in Europe. The granite, generally the most elevated, is separated from the secondary strata by gneiss and mica slate, and lower palæozoic slates, into which they pass almost indefinitely. In the departments of Calvados and La Manche these two systems appear as zones around the granite, the gneiss being within the clay slate. Quartz rocks of blue colour, and pegmatites with tourmaline, are associated with them; and they are traversed by veins of quartz and granite.[2]

In the Pyrenees.—The granitic masses of the narrow chain of the Pyrenees having been uplifted in much confusion, are very irregularly bordered; in several places they are overlaid by gneiss and mica slate, but generally by the latter series. Charpentier regarded the gneiss of the mountains which border the valley of Soulan as intimately connected by gradation and alternation with the subjacent granite, so as to be necessarily united therewith into one formation. In many instances gneiss and granite are described as alternating in very thin layers. In other cases, vast blocks of micaceous gneiss of 100 cubic fathoms bulk are buried at intervals in granite, always preserving one constant relative position or direction of the laminæ. These are thought by Charpentier to be of contemporaneous origin with the granite, which passes into them at the sides, and thus interlaminates the gneiss.

Mica slate, in the same manner, is intercalated with granite in a

[1] Geol. Trans., vol. v.

[2] De Caumont, Geol. du Cavaldos.

great many places, and quartz and felspar bands occur in the granite. In many places in the Pyrenees the "granite" contains beds of stratified granular limestone such as in other districts lies in the gneiss, with graphite, talc, fluor spar, mica, hornblende, &c.

Boué, Dufrenoy, and other writers, have proved beyond a doubt the powerful action of heat along the Pyrenean chain, as shown not only by the usual subcrystalline character of the slates, but also by the metamorphism of chalk into the condition of crystalline limestone, with the development of abundance of metallic and granitic veins at the line of junction of the altered, stratified, and igneous rocks. The age of the eruption of granite along this chain is determined by observations of Dufrenoy to be, at least in part, posterior to the Chalk.

Igneous theory does not necessarily require that all these beds of seeming granite should be altered gneiss, nor that the beds of porphyry should be considered as altered clay slate. Alternating igneous and aqueous action is exemplified in modern operations of nature; but certainly in many cases, both in Cornwall and Cumbria, it appears the more correct view to suppose a gradual and partial *rearrangement* of the materials of the rock through the long-continued action of heat.

In Central France.—The great central plateau of old rocks in France, from which the Loire, Vienne, Dordogne, &c., take their source, is chiefly a granitic and porphyritic tract, surrounded by oolitic and carboniferous rocks, but slates and gneiss rocks appear in the valley of the Vienne, and occupy a large part of the southern boundary. Near Limoges are alternating beds of granite and gneiss, and some subordinate beds of pegmatite and hornblende rock: the gneiss passes by one variation to granite, by another to mica slate. The ranges of strata near Limoges are north-east and south-west, and they are crossed by decomposing elvan courses to north-north-east. Tin veins occur near Vaulry in gneiss as well as in granite. Towards the borders of the district the gneiss becomes less granitic, more associated with hornblende slate, and encloses deposits of micaceous limestone. Serpentine lies in this gneiss in many places. The pegmatites and kaolins of St. Yrieux, which have resulted from decomposition of this rock, form numerous veins and strings in the gneiss and hornblende slates, which sometimes intercalate themselves between the laminæ. Quartz rock of bluish colour exists in the Black Mountain and elsewhere. Oxide of iron abounds at many points in the gneiss; galena, phosphate of lead, carbonate of copper, antimony, and hæmatite are the products of the veins.

The most remarkable alterations of secondary limestones take place, according to Dufrenoy, along the line of junction with the granitic and porphyritic masses. Thus the Lias and Oolite become metamorphic, and are traversed by metalliferous veins, just as the slates in Cornwall and Brittany are metalliferous, principally in the same situation.

Other Localities in Europe.—After these details of the circumstances attendant on gneiss and mica slate at so many interesting

points, we can only add a few general observations on the range and extent of these rocks in other countries. Gneiss and mica slate in small quantity occur in the Vosges, and gneiss more abundantly in the Black Forest.

The long irregular chain of the Alps contains a vast quantity of gneiss and mica slate, variously extended around the talc-bearing granite cores of Mont Blanc and St. Gothard, from the Mediterranean almost to the Danube.

Gneiss and mica slate do not reappear around the granitic base of the Carpathians. Their place is supplied in this chain by a vast deposit of clay slate.

The mountains which encircle Bohemia are, on all the southern half, granite. Gneiss and mica slate are superadded on the west, and the former rock in particular abounds in the Erzgebirge. The Riesengebirge granite is bordered on the north by gneiss, on the south and east by mica slate, and these rocks are associated with granite in the range which divides the drainage of the Oder and the Elbe.

These rocks are most extensively spread over the northern parts of Europe, and extend from Copenhagen round the Gulf of Bothnia, and along the Ural chain toward the Caspian Sea, and in the Caucasus.

Fossil-Bearing Schists of Norway.—Dr. Hans H. Reusch has shown that fossils occur in the schists of Norway to the south of Bergen, in the neighbourhood of Osören. The fossils occur on two horizons. In the southern horizon, grey, blue, crystalline limestone occurs in black clay slate, and bears fossils which are only indicated by clear outlines. The limestone is concretionary, and some of the concretions at Kuven contain the corals Halysites and Syringophyllum. Both these genera also occur in the calcareous band on the Os river; and in that locality and at Bauerhof Valle a few Gasteropods are seen in section. On the other horizon the fauna is richer, and is seen on the road to the north-east of Ulven. The road traverses a grey slate, apparently micaceous, which contains layers of calcareous concretions. These beds yield in the different exposures Favosites and Graptolites. The richest locality is in the Bauerhof Vagtdal, where the rock is a grey Muscovite slate with inclusions of brown mica, and shows under the microscope a good deal of quartz and rutile associated with the mica. The fossils are Trilobites, cup-corals, chain-corals, and Brachiopods, and their mode of occurrence indicates that the foliation is in a different plane from the bedding. The Trilobites comprise *Calymene* and *Phacops*. The Gasteropods are referable to *Subulites* or *Murchisonia*, and perhaps *Pleurotomaria*. The Brachiopod genera have not been determined. The corals are *Cyathophyllum*, *Halysites catenularius*, probably *Syringophyllum organum*, and some other types. The Graptolites comprise *Rastrites* and *Monograpsus*, and there are indications of Crinoids. This fauna indicates strata of Wenlock age.

In 1865 Sismonda described an Equisetum from an isolated block of gneiss, probably derived from the Veltline.

Metamorphic Rocks in America.—In America, Humboldt describes gneiss as less abundant along the high chains of the Andes than along

the lower mountains of Caracas, in Orinoco, Brazil, New Spain. It is occasionally auriferous, and contains micaceous crystalline limestone. The most considerable masses of mica slate mentioned by this traveller are those of the Cordillera of the shore of Venezuela. This rock in the Andes is less rare on the north than on the south of the Equator. Nowhere, perhaps, is the total suppression of mica slate more frequent than in the Cordilleras of Mexico and South America.

The eastern primary range of North America passes through the United States from the St. Lawrence to the Mississippi in a direction nearly parallel to the coast, and at first 100 miles distant from it.

The prevailing and characteristic rock is a syenitic gneiss, in which the divisional planes are obscure, and frequently evanescent, when the rock is undistinguishable from the syenite which forms part of this great metamorphic group. Gneiss retains in general its place next the granite, which, however, is of small extent; it is often succeeded by hornblendic, micaceous, and talcose schist, and granular, sometimes dolomitic limestone, seldom pure enough for fine statuary. It is traversed by granite veins at Haddam in Connecticut.

This is the principal metalliferous band in the Eastern United States, yielding magnetic iron ore in veins and beds, near Lake Champlain, in New York, New Jersey, Pennsylvania, and Maryland; on the southern side of Lake Superior, in the vicinity of Montreal, in Wisconsin, in the Iron Mountain and Pilot Knob in Missouri, and in Arkansas. Copper ore occurs in Lake Huron and on the northern shore of Lake Superior. Lead ore lies in these rocks in northern New York; lead and copper in Pennsylvania; zinc or red oxide, mixed with franklinite, occurs in New Jersey; phosphate of lime has been found in New York and New Jersey; kaolin marble, building stone, firestones, hones, steatite, plumbago, and many fine crystallised minerals, as apatite, zircon, spinelle, sphene, augite tourmaline, may be added to this list.

The range of the rocks is from the high country north of the St. Lawrence, westward to the sources of the Mississippi, and southward along the elevated parts of Maine, New Hampshire, New York, New Jersey, Pennsylvania, Maryland, Virginia, and North Carolina, to Alabama, with isolated belts in Missouri, Arkansas, and Texas.

Gneiss of North America.—Gneiss varies in mineral composition, and presents analogies towards different igneous rocks. At the north end of the Lake range in Nevada, the felspar is almost entirely triclinic, with a little orthoclase. There are also present biotite, quartz, and green hornblende, so that it corresponds to quartz-mica-diorite, in the same way that common mica gneiss corresponds to granite, and hornblende gneiss corresponds to quartz syenite. The quantity of prisms of apatite is enormous in this rock, as in all gneisses which abound in hornblende. In Clover Cañon many varieties of gneiss occur, some representing the diorite gneiss, but with the titanite in greyish yellow sharp sections; other Clover Cañon gneisses contain inclusions of liquid carbonic acid. In Europe, liquid carbonic acid is found in quartz in the granitic gneiss of the St. Gothard, and grey

gneiss from Freiburg in Saxony. In another part of the Humboldt range, the texture of the gneiss approaches more nearly to granite; and in the Secret Pass the rock contains crystals which resemble zircon, though no zirconia has been detected on analysis.

Hornblende gneisses generally predominate in the Ogden and Farmington Cañons in the Wahsatch range, Utah. One type is made up of orthoclase, with a good deal of plagioclase, quartz, brown mica, much hornblende, and apatite. The quantity of plagioclase is in some cases much greater. At other times a mineral like zircon is present, and in some of these the quantity of hornblende is small. Here too some of the hornblende gneiss contains garnet.

In the same district mica gneiss is found, which is free from hornblende, is rich in felspar and quartz, and poor in brown mica and deep red garnet.

Zirkel contrasts the mica gneiss with the hornblende gneiss, showing that in the former orthoclase preponderates; there is little plagioclase; the quartz is full of fluid inclusions; apatite and zircon are rare or absent, and titanite is entirely absent. In hornblende gneiss plagioclase sometimes preponderates. Fluid inclusions in quartz are comparatively rare. Apatite and zircon are usually abundant, and titanite is sometimes present.[1]

Succession of North American Crystalline Rocks.—The lowest group of the Laurentian Rocks of North America is named the *Ottawa* series. It consists of granitic gneisses, red and grey, often highly contorted, formed of orthoclase, with quartz and hornblende. Next in succession is the *Grenville* series, quartzose gneisses, and quartzites, with great beds of Dolomite, and the Limestone which yields Eozöon. It is said to be 17,000 feet thick. The *Norian* or Labrador series is supposed to rest unconformably on the older gneisses. These gneisses contain Labradorite or Anorthite, are 10,000 feet thick, and spread over Labrador and north of the St. Lawrence. The *Huronian* series is a yet newer group of metamorphic rocks, consisting, according to Dr. Bigsby, of chloritic, siliceous, and hornblende slates; but it also contains limestones, serpentines, and rocks of a greenstone character. It has been compared to the Pebidian rocks of Wales. The *Montalban* series is a succession of micaceous schists and friable grey gneisses, passing into micaceous quartzites and hornblendic gneiss. Newer still is the *Taconian* series, which forms the Taconic hills. It consists of quartz rocks and schists, with crystalline magnesian limestone, some serpentine, and great deposits of iron ores. Attempts have been made to parallel these rocks in Europe, but the method of research has yet to be developed which would justify the correlation.[2]

[1] Zirkel, Micros. Petrog.

[2] See Hicks: "Succession of the Archæan Rocks of America, compared with the Pre-Cambrian Rocks of Europe," Proc. Geol. Assoc., vol. viii. No. 5.

CHAPTER XXII.

MINERAL VEINS.

Origin of Mineral Veins.—Facts observed in mining districts have strongly enforced the belief that the water which descends through fissures to regions beneath the earth's surface, becomes so heated as to dissolve and hold in solution a multitude of metallic and mineral substances. Different kinds of mineral matter may be deposited successively from heated water as its temperature becomes lower; and hence the belief that, as waters on their way downward dissolve the minute particles of metallic substances which are scattered in the rocks with which they come in contact, so those waters on their way back towards the surface, traversing the fissure of some fault which gives them passage, become cooled, so as to throw down in a small portion of the fissure, ores or other mineral matter which had been invisible while diffused in the rocks. This belief is strongly supported by the fact that in passing down in a lode, it is no uncommon thing for the metallic contents to change.

Mineral Veins now Forming.—Many ores, like those of copper, tin, zinc, and lead, have the metal combined with sulphur, and it is well known that many hot springs, like those of Sicily and Lake County in California, deposit sulphur at the surface; and in the district of Lake County the sulphur contains a little mercury in the form of cinnabar. The sulphur is here deposited upon volcanic rock, and the sides of the fissures are frequently coated with chalcedony, in which are both pyrites and cinnabar; so that the sulphur deposit has been worked as a quicksilver mine. In a sinter bed, precipitated from a hot spring in the county of Colusa in California, Mr. Oxland discovered deposits of silver; and in this county Mr. Melville Attwood discovered cinnabar on the surfaces of a fissure which had become covered by a subsequent deposit of brilliant metallic gold. At Steam Boat Springs in the State of Nevada, which are about seven miles N.W. of the silver mines of the great Cornstock lode, heated waters or steam are constantly given off.[1] The fissures appear to have been subjected to repeated widenings, and have their walls lined, sometimes to a thickness of several feet, with incrustations of silica containing hydrated ferric-oxide, and occasionally crystals of iron pyrites. A similar group of fissures occurs a mile to the west, but they now only

[1] J. A. Phillips, Phil. Mag, 1868, p. 321; also Q. J. G. S., vol. xxxv. p. 390.

give off steam and carbonic acid. The silicious deposits have here accumulated in the principal fissure to a thickness of ninety yards in each side of the opening. This silica is sometimes in the condition of chalcedony, but most of it is crystalline. The quartz contains oxides of iron and manganese, and small quantities of iron and copper pyrites. In 1878 this older fissure was opened by a tunnel to a depth of fifty feet below the surface, when the vein stuff yielded cinnabar, from which 3 per cent. of mercury was obtained, while the deposits accumulated at the surface, from the overflow of the water, only contain traces of mercury. Similar accumulations of cinnabar occur near the hot springs of Calistoga, at the foot of Mount St. Helena. In the great Comstock lode the vein has the gangue consisting of silica and calcite, and yields silver and gold. At a depth of 2660 feet the water issues from the rock at a temperature of 157° F. These waters contain forty-two grains of solid matter to the gallon, partly sulphates, partly carbonates, and a little chloride. Hence we may infer that the metallic and non-metallic substances alike have been often deposited in the fissures of ancient faults by the waters of hot springs, and that when the temperature of the water is high, these metals may reach the surface, but as a rule the temperature is not sufficient for the surface deposition in quantity of anything but salts of lime and quartz, and in such cases the metals only reach the surface in consequence of subsequent denudation of the upper part of the vein stuff. It is well known that nearly all metalliferous veins occur in regions characterised by intrusive igneous rocks, volcanic phenomena, or faults. Such influences, by furnishing the heat required to dissolve the metal, must usually be held accountable for the formation of the veins.

Mr. J. Baddeley has pointed out that a great circle cutting the equator in 10° E. long. and 170° W. long. and reaching to lat. 45° north and south, coincides with the principal gold-producing mines of the world.

Source of Metals.—Nothing can be learned concerning the origin of metals. Hence, there is no greater *à priori* difficulty in deriving metallic veins from invisible materials in the surface rocks, than there would be in obtaining them from imaginary deep-seated masses of metal. Deep-sea exploration, however, has discovered an unexpected abundance of manganese in concretionary nodules on certain sea-beds; and it has long been known that the precious metals exist in the ocean in sufficient quantity to become deposited on the copper-sheathing of ships, and affect its commercial value when removed. Dr. Forschammer, by chemical examination of sea water and certain marine organisms, made a valuable contribution to materials for a theory of mineral veins of segregation. He found the following chemical elements:—*Oxygen*, *Hydrogen*, *Chlorine*, *Bromine*, *Iodine*, *Fluorine*, *Nitrogen*. *Sulphur* forms salts of baryta, strontia, lime, magnesia; and *Phosphorus* remains as phosphate of lime when water is evaporated. *Carbon* deoxidises the peroxide of iron either to protoxide or sulphide, and thus colours deep-sea sands and clays. *Silicon* is seen forming the skeleton in the calcined cup sponges of

Singapore, except that the large pores are lined with oxide of iron. *Boron* is found in the rock salt of Strassfurth in Germany, and this is presumably of marine origin, while the plant Zostera marina contains much Boracic acid. *Silver*, though difficult to detect in sea water, is yet so abundant in the coral Pocillipora alcicornis, that one cubic foot of coral yields about half a grain of silver. *Copper* is frequently found in the lime salts of sea animals and plants, and in the coral Pocillipora there is six times more copper than silver; the ash of Fucus vesiculosus contains copper. *Lead* is more abundant in shells and ashes of sea plants than even copper. Pocillipora alcicornis contains eight times as much lead as silver; lead also occurs in the Fucus vesiculosus. *Zinc* is found in the ashes of sea plants, such as Fucus vesiculosus, and in Zostera marina it occurs to the extent of 1 part in 3000. As the mineral Blende, it is common in the Ammonites cordatus from the Oxford clay of St. Ives. *Cobalt* occurs in Zostera marina, in the large cup sponge from Singapore, and in fossil sponges from the chalk. *Nickel*, in minute quantities, seems to occur with Cobalt. Iron in great quantity is found in the ashes of sea-weeds and lime-salts of sea animals. *Manganese* forms nearly 4 per cent. of the ash of Zostera marina. *Aluminium* is more abundant than any metal except iron and perhaps manganese. *Magnesium* usually forms 1 per cent. of shells, though it forms 13½ per cent. of the shell of Serpula filigramma. *Calcium*, as carbonate of lime, forms ·003 of sea water, and is abundant in all shells, &c. *Strontium* is found in the ashes of Fucoids. *Baryta* is common in sea animals and abundant in the ashes of sea plants. And there are the universally diffused substances *Sodium* and *Potassium*.

These substances being thus diffused in nature and accumulated by organisms, the strata become charged with them; and hence, when metamorphic changes raise the temperature and dissolve the whole substance of the strata, with the production of multitudes of fractures, joints, and faults, it is easy to conceive the steps of change by which these minute particles become dissolved, extruded by crystallisation of the rock, and deposited in veins.

Daubrée's Views on the Origin of Ores.—Mr. Daubrée urges[1] that the ores which occur as sulphides are all to be attributed to the action of sulphurous waters upon metallic substances. Thus Roman coins buried in mud in the warm spring at Bourboune-les-Bains are more or less converted into copper pyrites and other cupric sulphides. Lead pipes have yielded a coating of galena, which M. Daubrée attributes to the decomposition of phosgenite under the reducing influence of organic matter. Iron pyrites appear to be frequently formed under the influence of decaying organic matter, especially plants, but it assumes a more characteristic form in the waters of sulphurous springs. In Iceland it is developed by the action of sulphuretted hydrogen on the iron in basaltic rocks.

Difference between Dykes and Veins.—Though in some instances

[1] "Geologie Experimentale," 1879.

the distinction between rock dykes and mineral veins is imaginary, they are in general clearly contrasted by the nature of the substances which they contain. In dykes the crystallised minerals are of the same kind as those great interior masses of consolidated rock from which they often are evidently ramifications. In veins metallic substances occur which are mostly not known to exist in nature except in these situations, and in others very similar or distinctly related to them by position and minerals. To this general rule quartz is one of the most striking exceptions; yet even in this instance it is remarkable that the quartz of veins is of a different aspect from that mingled with the ingredients of granitic rocks. We must therefore take the presence of metallic matter and certain non-metallic substances usually connected therewith, and commonly called vein-stuff, as the leading characteristic of the mineral veins, whose history we are now to examine.

Substances in the Veins.—The simple minerals which occur in veins and analogous situations are far more numerous than those which are found as component parts of rocks. Igneous rocks, and especially those of modern volcanic origin, hold a very great variety of non-metallic substances, some of which also occur in veins; but it is almost exclusively in veins that we find the metals in their pure state, or alloyed with one another, or mineralised by combination with sulphur, oxygen, chlorine, &c., or converted into salts by union with various acids. Every elementary substance yet discovered by chemists exists in the earth; and it is probable that none of these are entirely absent from the solid contents of mineral veins.

Alloys.—The metallic substances seldom occur pure. Sometimes they are found in alloys, similar for the most part to those now producible by the chemist, thus silver, antimony, cobalt, nickel, iron, are alloyed with arsenic; silver and nickel with antimony; lead, gold, silver, and bismuth with tellurium; silver with mercury; platinum with gold, &c. The only known circumstance which stands as antecedent to the production of such alloys is heat, produced by either chemical action or pressure; and perhaps there is no *single fact* connected with the theory of veins on which a belief in the influence of heat in their production might be more securely based.

Oxides and Salts.—The metallic oxides prevalent in veins are produced under various relations to heat, moisture, and contact with gaseous substances; and have various degrees of permanence when exposed to high temperatures, either separately or combined. Metallic salts are not rare in veins, and in the same way vary in their origin and degree of permanence. Metallic oxides and salts, in very many instances, are derivative compounds from sulphides and other primary combinations. This is frequently the case with oxide of iron, carbonate of copper, and probably carbonate, phosphate, and other salts of lead.

Non-Metallic Minerals.—Besides the metallic ores which impart to many veins their most striking, if not most constant characters, various earthy minerals lie in these repositories, and, as will afterwards

appear, under certain definite relations to the enclosing rocks as well as to the included metals, and with a less distinct dependence on the local situation *or mining district.* These earthy substances are usually called the gangue, vein-stuff, or matrix of the ore. Generally they are crystallised, as quartz, fluor spar, calcareous spar, phosphate of lime, the sulphate and carbonate of baryta, strontian, &c.; sometimes they appear massive, as quartz and several other minerals, when the vein has no cavities in it; and sometimes the vein-stuff is entirely soft argillaceous matter, of different aspect in different mining districts.

Rider.—In some veins masses of the neighbouring rocks are enclosed and penetrated to a great extent by little *strings* of the ore and spar, so as occasionally to be worth the trouble of working. The vein is said in this case to bear a rider. It, in fact, sometimes becomes under these circumstances a double vein. More rarely pebbles and other marks of water action are stated to occur in soft veins.

Mode of Aggregation of the Ingredients.—A variety of appearances deserve special notice as indicating some of the conditions under which the vein was filled. In some cases, for instance, the whole breadth of the vein is occupied by one kind of substance, as lead ore, or quartz, or sulphate of baryta; in other instances, the metallic matter is interspersed in small masses through a basis, such as quartz; but, generally, the different substances which fill the vein are ranged in a definite order of succession from the sides of the vein toward the middle, in which, commonly, the metallic matter occurs in an irregular vertical table, called *a rib of ore.* These conditions are best observed in the proper veins, but are also to be noticed in the *nests* and detached masses of ore and vein-stuff which sometimes occur in the vicinity of the veins.

General Idea of a Mineral Vein.—The *ordinary* conception of a mineral vein is well exemplified in some Derbyshire specimens, not rare in collections, which, when cut across, show, in the middle, masses or a continuous rib of galena, and on each side of this, to the extreme edges of the mass (or narrow vein), layers of fluor spar and carbonate of baryta in frequent alternation, all the materials being crystallised together without leaving any cavities, yet preserving their own character of structure.

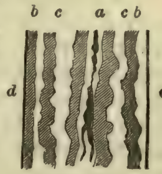


Fig. 77.

Thus, in the diagram, *a* is the middle rib of galena, *b b*, *c c*, the alternating bands of barytic spar and fluor spar; *d d*, the masses of rock which enclose the vein, are called the walls or cheeks of the vein.

Supposed Successive Deposition of the Substances.—The contemplation of these specimens seldom fails to impress upon the mind a conviction that the several bands of mineral substances were deposited on the cheeks or walls of the vein in succession, the middle being filled last of all; and this theoretical notion has been illustrated by comparing a mineral vein to a narrow gallery whose walls were covered by many successive coats of plaster of different

colour and composition. Werner adopted the notion of the unequal antiquity of the vertical layers of the vein so implicitly as to speak of the middle ribs as always younger. It is difficult to resist this impression, especially when, in addition to the circumstance of the succession of the laminæ, we observe that these laminæ are so crystallised as to turn their free terminations towards the centre of the vein, and in that direction to imprint the next layer with their own forms, just as crystals forming in a vessel shoot their point toward the part still remaining liquid, and in that direction are covered by the subsequently formed crystals. Very similar inferences are suggested by certain agates, and more distinctly by geodes in basalt, and the crystallised cavities in limestones, in the interior of shells, &c.; in which cases the hollow towards which the crystals pointed still remains unfilled.

This first impression becomes somewhat modified when, instead of confining ourselves to a cabinet specimen, we examine the whole extent of a mine; for here, in the first place, it is very often found that the regular succession of minerals from the side to the centre is a limited though repeated phenomenon; that the rib of ore is of short horizontal, and sometimes still shorter vertical extent, diminishing to nothing, or diffused in small grains through the contiguous spars; that different metals are found in the same vein at different depths, and at distant points along its course; and that both the quantity of metal and the presence of spars are dependent on the hardness, and perhaps on some other physical properties of the rocks which the vein divides and replaces.

Chemical Relations of Metals.—The phenomena of crystallisation before alluded to can hardly be thought to prove the successive introduction of the mineral laminæ into the vein; though very probably they do demonstrate the order of crystallisation of these substances.

In some cases we observe indications that one kind of mineral has been formed round another as a nucleus; as, for example, sulphide of copper round iron pyrites in a part of Caldbeck Fells, Cumberland, and more frequently in many places carbonate of copper and carbonate of lead round the sulphides of those metals. As we have remarked, it is very often the case that the metallic matter of the vein is collected into the middle and forms there a distinct tabular mass, called a rib of ore, more rarely it is disseminated into the gangue. Generally, only one kind of metal abounds in the same part of the vein, but the same vein may yield lead above and copper below, copper above and tin below, or lead in one place and copper in another. The observation is frequent that ore is collected into certain vertical portions of a vein which are worked above and below a level, and between which little but vein-stuffs is found in the horizontal drift. There is a vague notion amongst miners that veins are most productive in the deep workings, and it is at least probable that they are less rich very near the surface.

Association of Minerals.—Werner insisted on the fact, that certain associations of minerals can be traced in veins. He noticed the

concurrence of lead glance, and blende, or calamine, and copper pyrites; of cobalt, copper, nickel, and native bismuth; of tin, wolfram, tungsten, molybdena, and arsenical pyrites; of topaz, fluor spar, apatite, schorl, mica, chlorite, and lithomarge; of brown ironstone, black ironstone, manganese, and heavy spar. He says where tin occurs, ores of silver, lead, and cobalt, and vein-stuffs of heavy spar, calcareous spar, and gypsum are rarely found. Cinnabar and other ores of mercury scarcely ever occur with the ores of other metals, except iron ochre and iron pyrites.

Rolled and Fragmental Masses.—That fragmental masses of the neighbouring rocks should be found in mineral veins, cannot be thought surprising. It is a common occurrence in mining districts, both in Primary and Secondary rocks. Thus gneiss at Joachimsthal, clay slate in Cornwall, limestone in Cumberland, are included in the veins. Werner mentions a vein in Danielstollen at Joachimsthal, fourteen inches wide, which at one hundred and eighty fathoms depth was almost entirely composed of rolled pieces of gneiss, some of them nearly spherical. In the Stoll Kefier, near Riegelsdorf, a vein of cobalt was cut through by another vein of sand and rolled pieces. These examples seem trustworthy, but we must always be careful to discriminate between rolled pebbles and concretionary masses.

General Forms of Veins.—Mineral veins are usually distinguished by miners into several kinds, according to their form and direction, because these circumstances are the most influential in the arrangement of their works. *Rake veins*, the most common and characteristic, may be considered to fill long, narrow joint-fissures or faults, which pass in a vertical or highly inclined direction downwards from the surface through a great thickness of the subjacent rocks, whatever these may be, and preserve nearly the same angle of inclination and the same linear direction through their whole course. *Pipe veins* are also highly inclined, and pass downward in the same manner, but they rather resemble irregular channels than fissures, and are subject to great swellings and contractions of their diameter. They sometimes pass downward along the stratification; in other cases penetrate through the substance of the strata. The copper mines in the neighbourhood of Ecton, in Staffordshire. are in pipe veins. The irregular cavity of copper ore, which forms the celebrated Parys mine in Anglesea, and the iron mines of Dannemora in Sweden, may be pipe veins, or stockworks. *Flat veins* or *streaks*, as far as we are acquainted with them, seem hardly to deserve a special name, being only portions of rake veins which have been changed in their inclination, and made to pass for limited distances parallel to the beds. In the limestone districts of the North of England, this happens principally in connection with certain limestone beds. The term *Gash veins* denotes such as range for considerable lengths, like rake veins, but are wide at top, and grow narrower downwards, till they entirely vanish. This is rare, though many veins grow narrower downwards.

Strings.—Perfect parallelism of the sides or walls of a rake vein, which is the most regular of all, is a rare phenomenon. Most com-

monly, indeed, there is a definite boundary to the mineral masses presented by the rocks on each side, but this is only on the great scale; and the operations of mining disclose to us innumerable cracks and fissures in these boundary walls, which, when filled by metallic or sparry matters, are called strings, and are frequently worth the labour of following even to great distances from the parent vein, if, indeed, we ought not often to reverse this expression. The notion of miners generally appears to be, that these strings are to be viewed as *feeders* of the vein, and in proportion to their frequency in many instances is the productiveness of the vein. In the accompanying diagram, the vein is represented as receiving small branches or strings from the neighbouring rock. A rock thus penetrated by strings is sometimes said to be *ridered*. The rock masses which are often included in the vein are termed horses; they are usually well separated from the walls. In many rocks these ridered parts are very greatly altered from their original state.

Fig. 78.

It sometimes happens that, in passing through rocks of varying hardness, as limestone, shale, &c., the veins turn flat for a short distance on the hardest and most connected beds (as, for example, on the Tyne bottom limestone of Cumberland), and afterwards continue their ordinary course. These flat parts usually send off strings into the limestone, which may thus be ridered to a considerable distance.

Disseminated Veins, &c.—Sometimes the mineral is disseminated through the parts of the rock adjoining a vein, or collected in small nests and other closed cavities. This happens not only in the Cornish mines, in killas and granite, but in those in the mountain limestone tracts of the north of England, and even in magnesian limestone. Generally speaking, we may be sure that this metallic impregnation is so related to the veins, that it is an effect of the same agent. Whatever filled the veins, also brought to small distances from them some of their constituent minerals. Certain metals and ores are more liable than others to this lateral diffusion. Native silver, silver glance, red silver ore, native copper, tin ore, iron pyrites, and red iron ochre, are specially noted as occurring in this way; though copper ore, pyrites, and lead glance seldom exhibit this effect. Galena, however, blende, bitumen, calc spar, and quartz, are found in closed cavities of shells, in mountain limestone, and in other strata.

Tin Floors, Stockworks, &c.—The dissemination of tin ores through some of the rocks of Cornwall was noticed long since by Hawkins, under the title of tin floors.[1] He observed that the whole tenement of Botallack is said to be full of tin floors. At Zinnwald, mineral beds or floors have long been the object of mining adventure. There granite alternates with the tin floors, which consist of quartz and mica, with tin ore, fluor spar, and wolfram. At Breitenbrunn a

[1] Geol. Soc. of Cornwall Trans., vol. ii.

floor of this kind has been very extensively worked in a gneiss rock.

The stockwork of the German miners is to be considered as a mass of rock impregnated with metallic matters, in numerous small veins, which come together irregularly, so as to make particular parts extremely rich. The working of such mineral repositories is directed by quite other principles than those which serve for straight veins of definite magnitude. The stockwork is generally opened like a vast quarry, and the excavations are prosecuted irregularly in the most favourable directions. Perhaps the copper mine of Parys mountain in Anglesea, the iron mine of Dannemora in Sweden, the tin ore mine of Geyer in Saxony, are examples of immense stockworks. Werner considered the stockwork as peculiar to tin ores.

Relations of Veins to each other.—The influence which veins exert on each other may be in some measure ascertained by an examination of the phenomena at the points where they come into contact with or cross each other. At these points it is very often found that the quantity of ore is suddenly increased to a large amount, and for some distance, in either one or both of the veins. Many veins are productive only near such points, or yield there peculiar ores and minerals. This does not depend upon the enlargement of the vein merely, but may indicate the influence of thermal or electric conditions in the disposition of the materials of mineral veins. We have heard miners say that in certain cases neighbouring veins are subject to a kind of reciprocity, so that they are not both productive in the same ground, but where one is rich the other is poor.

Age of Veins.—When two veins cross, it almost invariably happens that one of these cuts, or is continued, right through the other, as a wall is sometimes continuous through another wall of brick from top to bottom. Thus a vein of copper ore may cross and cut through a vein of tin ore; a vein of lead ore may cut through a vein of copper ore, and all these be cut through by some other sparry vein or porphyry dyke. It is supposed, by almost every writer on the subject, that the relative antiquity of the veins which thus intersect one another may be immediately determined; and that in every case the vein which is cut through is the older of the two. Werner took this as the basis of his classification of veins, and most practical as well as theoretical miners agree in his views; but they are nevertheless controverted.

We cannot make a step in this argument, except upon the admission that the veins are posterior in date to the rock which encloses them; in other words, that the space in which the mineral masses of a vein lie, once existed as a fissure in the rocks, and was subsequently filled up by the accumulation of the sparry and metallic matters.

The Neighbourhood of a Vein.—It is a general fact that the walls of a vein partake in some degree of its characters, and that effects, apparently depending on the vein, propagate themselves into the neighbouring rocks. Thus the walls become more indurated, more

crystalline, and for considerable distances are filled with the matters of the vein; and even the very substance of the rocks is often impregnated with mineral combinations. In a country where the veins are numerous, large masses of the rocks may in this way be *ridered*, as it is termed in the North of England; and if such a gradation of characters could be relied on as a proof of contemporaneity of origin, this may in a few cases lead to the conclusion that the veins and rocks are coeval.

But the true conclusion on this point is that these effects are locally related to veins; the ridering of the neighbouring rocks is coeval with the production of the vein; but since these rocks are clearly defined from the veins, and fragments of them are enclosed in the veins, and the mineralising influence which they have suffered obviously depends on the influence of the veins, we cannot hesitate to admit that these latter are of separate and subsequent origin.

Veins in Different Rocks.—It is found that when veins divide different sorts of rocks, their contents vary in an inconstant manner, according to the nature of the rocks. The most usual notion on this subject is, that the veins may be viewed as secretions from the rocks; and by some this is supposed to have happened after the production of fissures; by others, by a mere internal separation of the parts of the mingled metallic and earthy mass.

This notion of the slow separation of the ingredients of rocks is in accordance with the principles and facts of chemistry, and must be often appealed to, if we would explain by *true causes* the phenomena of mineral veins.

Contemporaneous Veins.—There are combinations of minerals in masses of various figure, which, upon very good grounds, are admitted to be contemporaneous with the rocks in which they lie; and if we choose to call by the name of veins all such distinct combinations of minerals, these certainly are contemporaneous veins. When in granite, greenstone, &c., we find particular portions of those rocks either linear, tabular, globular, or in any other figure, which have a different proportion of ingredients from the other parts, and in consequence become conspicuous and distinct, except at the edges, which graduate without any sign of fissure into the ordinary mass of the rock; these may certainly be pronounced contemporaneous veins, and they have been produced by a process of secretion or segregation during the crystallisation of the rock.

In some instances veins of calcareous spar or other minerals lie *wholly included* in limestone masses, and these are properly called veins of segregation; but they are *not contemporaneous veins*, for they have clearly been fissures filled at some period since the consolidation of the rock; and the proof is, that shells, corals, &c., are split, and sometimes displaced by these sparry veins, which undoubtedly occupy cracks left by the shrinking of the rock in the process of consolidation.

Allowing every just latitude to the doctrine of contemporaneous veins, we must admit that most veins are newer than the rocks which enclose them and have yielded their minerals.

Intersection of Veins.—The most simple case is when two straight veins cross without any change of direction, or any lateral displacement; and the order of effects appears to be the production of a fissure, and the filling of this by a vein which was afterwards broken through by another fissure, and this, in its turn, received another mineral vein. It seems difficult to doubt the truth of this explanation; for if the vein which cuts through the other be subsequent to the fissure in which itself lies, it must also be subsequent to the vein which that fissure divides. The occasional complication of the problem by the number of intersections does not at all change its nature.

Appearances at the Crossing.—It is sometimes observed that the vein which upon this theory is the oldest, suffers a particular kind of accident at its junction with the other. It is divided into several branches on one or both sides of the cross veins, and these branches enclose portions of the neighbouring rocks. There is some difficulty in this case, however it be considered, but the coincidence of this splitting of a vein with the crossing of another vein may often be only accidental; for such splitting frequently occurs in a wide vein, far from any cross course, as in a fault.

The fissures which have received the mineral veins are in most cases accompanied by slips or dislocations of the strata in a vertical direction, and the veins are of course subject to the same accidents of displacement. When two veins cross, and both are vertical, the lines of bearing of the two portions of the displaced vein must remain coincident after the fracture. If the divided vein be not vertical, its separated portions will have their lines of direction parallel, but not coincident; and in any horizontal plane they will *appear* to have sustained a lateral movement. Thus in the diagram (fig. 79), the cross vein *a* and the divided vein *b* are both vertical; but the divided vein *c* is inclined in the direction of the arrows, and its *apparent* lateral displacement is really due to a vertical movement. If two divided veins are inclined in opposite directions, and be dislocated by the same cross vein, they will appear to have moved laterally in opposite directions, as *c* and *d*.

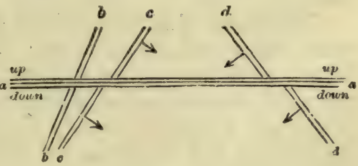


Fig. 79.

Were we to include the cases of the inclined cross veins, and also those where the inclination of these veins varies both in amount and direction, the results would become too complicated for explanation without mathematical symbols; and we must, besides, remember that the displacement of the strata is really very seldom in a vertical direction, but generally accomplished by an angular movement from some fixed point, or round a virtual centre.

Geographical Relation of Veins.—Werner long ago indicated that mining districts are almost entirely confined to the vicinity of mountains or elevated land, because in these situations the rocks were most

dislocated by slips, and divided by fissures at the period of their elevation. It is not the absolute height of the ground, but the circumstance of its having been much exposed to subterranean convulsion, infiltration, and denudation, that determines the prevalence of mineral veins. The rich mines of Cornwall are in comparatively low situations, but they are all in the vicinity of elevated rocks which have been heated.

There appears to be no limit either of height above or depth below the sea, which defines the productiveness of veins, though in some countries like America, higher situations are most favourable.

It is sometimes found that the contents of a vein vary with the depth, without any particular geological conditions; as, for instance, in Cornwall copper is prevalent in the mines at greater depths than tin; and in the slate tract of Cumberland veins which bear lead near the surface yield copper at a depth. In other cases there appears a peculiar determination of the metallic ingredients to particular situations. The mines about Ecton yield copper; those of Derbyshire and the Pennine chain generally yield lead, but toward the eastern and western limits of the district, copper becomes less uncommon.

The length of a vein or fissure is perhaps hardly in any case certainly known; because, when it ceases to be worth working, it is for all the ordinary purposes of mining said to be dying out, or cut out, or ended. The richest veins are productive for limited lengths, but the fissures which they fill may be, and often are, extended far beyond the spaces occupied by metallic impregnations. Some of them are known to extend, and to be productive for many miles in the Harz, in Cornwall, and in the North of England. The width is various in different veins, but generally nearly constant in the same vein. A width of twenty feet is very unusual. Most veins are less than six feet wide.

Directions of Mineral Veins.—The most general direction of the great dykes and faults in the North of England may perhaps be defined to be nearly east and west. But this is much more certainly true with respect to the mineral veins of the limestone districts of Weardale, Allendale, Alston Moor, and all the mining districts of Yorkshire; and it is equally recognised in the Primary tracts of Cumberland, Westmoreland, and Lancashire. This is so general a fact, that the east-and-west veins are called right-running veins, while the few which range more nearly north and south are called cross courses. These latter are seldom rich in metal. They often cut through and shift the right-running veins laterally, as both of them shift the strata vertically. There is often to be observed a sort of compensation in the dislocating effects of veins. In Weardale most of the veins throw down to the south, while the parallel courses in Allendale and Alston Moor throw down to the north. The lead veins of Flintshire and Cardiganshire have the same east-and-west direction, and so have those of Mexico.

The lodes and veins of Cornwall are most generally east-and-west veins, or nearly so; and these are the *oldest veins* in that district, being traversed by oblique veins and by cross course elvans and

flukans. But all the east-and-west lodes are not of the same age, the tin being older than the copper; neither are all the east-and-west tin veins of one age, for those that underlie to the north are generally traversed by those that underlie southwards. These curious generalisations are not to be overthrown by particular discordances; and they are certainly supported by analogous though less varied occurrences in other countries.

Directions of Veins of Different Antiquity.—The general order of their dates may be thus expressed :—

1. Oldest, east-and-west tin veins underlying to the north.
2. East-and-west tin veins underlying to the south.
3. East-and-west copper veins generally east to south.
4. Oblique or *contra* copper veins, generally east 30° to 45° south.
5. Cross courses not metalliferous, north and south.
6. Copper lodes of more recent date and lead veins.
7. Cross flukans or clay dykes nearly north and south.
8. Slides in all directions, but generally east and west.

The porphyritic and other dykes called elvan courses are very generally divided by the veins, and seem to be of greater antiquity. Werner observed this geographical relation of mineral veins, and stated the two following cases. In the mining district of Freiberg are two classes of veins very different from one another. One of these classes consists of veins which run from north to south. The veins of this group contain lead glance, black blende, iron, copper, and arsenical pyrites, quartz, and brown spar. This is the oldest vein-formation. The second class of veins, which always traverse the former, and are never crossed by them, contains lead glance, radiated pyrites, heavy spar, fluor spar, and quartz. They strike between the sixth and ninth hours of the mining compass (east to south-east).

The mining district of Ehrenfriedesdorf contains veins of tin and silver glance. The tin veins are always traversed by the silver. The direction of the first is between the sixth and ninth hour (east and south-east), that of the last from the ninth to the third hour (south-east, south, south-west).

Direction of Mining Districts.—There is observed in some mining districts another remarkable relation of metalliferous veins to geographical lines. Though in the North of England the most frequent direction of the *veins* lies east and west, the *mining districts* seem rather to be ranged in lines from north to south. The nature of this relation will be more easily understood if we add that both in Cornwall and in Cardiganshire, where the veins are also most frequently east and west, lines of greater productiveness range nearly north and south across the bearing of the veins. These curious notices suggest the inquiry whether the lines of productiveness are dependent on any principal axis of dislocation or strain, or on the occurrence of cross courses. The former case seems to be indicated by the phenomena in the North of England. Perhaps the latter may be more applicable to Cornwall.

Connection of Fissures and Main Joints.—It is certain that in

the limestone dales of the North of England mineral veins are sometimes directed along the *master joints* of the rocks, also that in the slate tracts of the Craven district veins and dislocations range along the *cleavage planes* of the slates. Dr. Boase noticed the same thing in the slate tract in Cornwall, and such observations might be multiplied. Mechanical considerations would have led us to anticipate this result; for the main joints and cleavage planes are often the lines of least resistance, and yield more easily to infiltration than other parts of a stratum or to any eruptive or depressing force.

Relation of Mineral Veins to the Rocks which enclose them.—The relation of mineral veins to the rocks which enclose them is very little understood. It is difficult to distinguish clearly between the *accidental* and the *necessary* association of the phenomena of veins and rock masses.

Metalliferous veins occur more or less frequently in every class of rocks, and equally in limestone, in argillaceous slate and shale, in quartz and sandstone rocks, and in rocks of mingled ingredients; in uniform slates, and fragmentary millstone grit, in granular sandstone, compact limestone, and crystallized limestone and granite; in sedimentary grits and shales, in porphyries, basalts, and metamorphic conglomerates. The existence of mineral veins in a rock is therefore wholly independent of the particular chemical and mineralogical nature and proximate origin of that rock; nor, when due allowance is made for the relative prevalence of the different kinds of rocks, does there appear any reason to admit that any preference or more frequent occurrence of metalliferous veins in rocks of particular kinds can be traced, *except in particular districts.* There yet remains the inquiry whether certain metals are specially associated with or related to particular sorts of rocks.

Diffusion of Pyrites, &c.—Hardly any substance is more abundant in the mineral kingdom than iron pyrites; it occurs both in veins and disseminated crystals or concretions; and, in one or other of these states, it is associated with almost every known rock. It occurs disseminated in limestone of various kinds, as crystalline limestone, carboniferous limestone, and chalk; in clay slates, shales, clays; and basalt. Veins containing iron pyrites traverse rocks of as great diversity. Copper pyrites is not disseminated through so many rocks as iron pyrites, but it occurs in veins which traverse limestone, sandstone, and shale, clay slate, mica schist, granite, &c. Ores of manganese are also very generally diffused through rocks of very different kinds. The converse is true. In one and the same kind of rock occur veins of copper, lead, silver, and tin.

Relations of Metals to Slate and Granite.—The tin veins of Cornwall sometimes pass through clay slate and granite; they produce ores in both. A vein that has been productive of copper ore in the clay state, passing into the granite, becomes richer, or, what is more remarkable, furnishes ores of the same metal differently mineralized. If we pursue it farther into the granite, the produce of metal is frequently found to diminish. A change of ground is looked upon

by miners as affording reason to expect an alteration for better or worse, suggesting secretion of minerals from the rocks.

Metalliferous Veins in Silesia.—Remarkable instances of this relation are given by Von Dechen.[1] The numerous veins which cross the steeply-inclined strata of greywacke in the Liegen district, are metalliferous in narrow bands *parallel* to the inclined beds of slate. The veins of the Kupferberg, in Silesia, bear ore only in the hornblende schist, and are impoverished in mica schist. At Joachimsthal the mica schist is traversed by quartzose porphyry in veins, which, as well as the contiguous rock, hold pyrites in mica slate. The rothegang of Elias consists of loam, and holds only uranite; where it runs between mica schist and a porphyry vein, and where it traverses the latter, its substance is a red hornstone, and it bears vitreous silver, native silver, arsenical cobalt, bismuth glance, kupfernickel, arsenic, and bismuth; but red silver, elsewhere abundant, is entirely wanting.

Condition of Veins in North of England.—In the lead veins of the north of England, which are situated in the Carboniferous limestone tract, a singular dependence is observed between the contents of the vein and the nature of the adjacent rock. The vein divides limestones, sandstones, and shales, and these are brought variously into apposition by the dislocations which accompany almost all the veins. The vein is sometimes productive of lead ore under every case of apposition in rocks. Where limestone, or schist, or solid sandstone forms the walls, its productiveness is at the maximum, but generally it is contracted in breadth and impoverished in its metallic contents, wherever it is included between walls of shale; and even where only one side is occupied by shale, the same effect is frequently observed. It would appear that the impoverishing influence of the shale is referable to mechanical causes. In the same way as the shales in a coal-pit swell out from the undisturbed parts to fill the excavated vacuities, so we may conceive them to have expanded into the natural fissure; this will account for the contraction of the vein. In the process of crystallisation, to which all the contents of a vein are subject, it seems conformable to analogy to suppose that the permanent walls of limestone and gritstone would permit a more early growth of sparry and metallic crystals than the crumbling edges of shale; a supposition, perhaps, confirmed by the occasional mixture of shale in the sparry mass of a vein, where it is "nipped," as the miner says, in beds of shale.

Quantity of Lead Ore from Different Beds of Limestone.—From some or all of these causes it happens in the north of England that *certain* limestones are very much more productive than the others; in different mining districts, *different* limestones are thus favourably distinguished, but in the country of Alston Moor, Teesdale, and Swaledale, the uppermost thick limestone is by far the most rich in lead.

Upon the whole there is no sufficient evidence to show that the

[1] "De la Beche's Manual," German Trans., 594.

local *production* of metallic substances is in any special manner dependent upon the chemical or mineralogical composition, or the circumstances of the formation of the adjacent rocks, though in many instances we observe the *aggregation* of the substances in the vein to have been influenced by peculiar conditions of the including rocks.

Alteration of Substance of Walls of a Vein.—The walls or cheeks which form the more or less definite boundaries of the vein are in some instances highly indurated, and very often fissured, so as to break parallel to the vein; in other cases certain sorts of rock (as clay slate, both in Cornwall and Germany) are greatly softened, and even converted to clay, along one or both sides of a vein. Werner mentions the decomposition of felspathic and hornblendic rocks for a fathom from the vein. We have also witnessed the fact of limestone, usually a blue or grey crinoidal rock, burnt, as the miners term it; that is, converted to a brown granular crystalline rock in Teesdale. Another remarkable effect in the walls is the production of slickenside, so long known in the mines of Derbyshire, which are situated in limestone, and filled with fluoric and barytic spars, and yield lead; in those of Cornwall, which are in killas, and with a matrix of quartz, and yield copper; in the magnesian limestone of Yorkshire, where copper or lead lines the limestone cheeks; and in the faults of the coal system of Yorkshire, where neither spar nor metallic matters are common. These and many other occurrences of rubbed surfaces along planes of fissures speak a clear language, and prove to the fullest conviction the mechanical movement of the sides of the fissure upon one another or upon the contained substances. The groovings of the surfaces, thus produced by rubbing, indicate, of course, the line of the movement; the circumstance that the polished faces are partially covered by lead ore, copper ore, &c., as the nature of the vein is, proves, moreover, that the movement was, in such cases, posterior to the introduction of the whole or a part of the mineral impregnation, so that the same fissure has been, in such cases, the plane of more than one convulsive movement.

Relation of Veins to the Different Ages of Rocks.—It is in the palæozoic rocks, and in the metamorphic and igneous rocks associated with them, that all the veins in Great Britain are worked. In a few instances veins of small value, producing lead and copper, pass through the magnesian limestone; but not a single example is known of a true metallic vein in the Oolitic, Cretaceous, or Tertiary strata. The connection of metallic veins with the older rocks is not an accidental coincidence, but a constantly recurring phenomenon; and the absence of such veins from the newer strata in England cannot be accounted for by any circumstances of the geographical position of these strata; for both around the metalliferous slates of Cumberland and limestones of Derbyshire the trias is extensively spread, and yet not one lead or copper vein occurs in it. Any one who should confine his attention to the British Isles might infer that the causes of the production of mineral veins had been almost wholly inactive ever since the Carboniferous epoch; and as a general

expression this may apply to the continent of Europe, though both in the Pyrenees, and around the central granitic tract of France, metalliferous veins apparently originating in these rocks, traverse strata of the oolitic and cretaceous systems.

Association of Veins and Dykes.—It must here be remarked, that both in Great Britain and throughout Europe intrusive veins and basaltic dykes are in the same manner abundant in the primary and rare in the secondary and tertiary strata. This is one of many general analogies tending to substantiate the opinion that rock veins and dykes, and metalliferous veins, often form two parallel series of products developed during the same geological periods by the same general causes, acting under different circumstances upon different materials. The disruptions by which igneous rocks were placed in contact with secondary and tertiary strata must have been first experienced by the older strata, from beneath which the disturbing force originated; hence it is easy to understand why the primary rocks are so universally, and the secondary and tertiary strata so partially affected by dykes and enriched with mineral treasures.

Modern Veins.—As an example of veins of more recent date, we may quote Von Dechen's notice of the veins of Joachimsthal. In this case the dykes of basalt which divide the mica slate are themselves cut through by mineral veins. These dykes are variously connected with great overlying masses of basalt which break into the Brown Coal formation. It is therefore evident that the silver, arsenic, and cobalt ores have been thrown into the veins at a later epoch than that of the brown coal tertiary deposit at the foot of the Bohemian Erzgebirge.

Werner's Eight Systems.—Werner distinguished eight principal systems of mineral veins in the mining field of Freiberg. The first and oldest produces abundance of argentiferous lead glance. It consists of coarse granular lead glance with from one and a half to two and a half ounces of silver per quintal, common arsenical pyrites, black blende in large grains, common iron and hepatic pyrites, sometimes a little copper pyrites, and a little sparry ironstone. The veinstones are chiefly quartz, sometimes a little brown spar, rarely calc spar. These circumstances occur most generally in veins ranging from *north to south.*

The second yields lead very rich in silver. It contains lead glance in large and small grains; black blende in small grains; iron and hepatic pyrites, and a little arsenical pyrites. In addition, dark-red silver ore, brittle silver ore, white silver glance, plumose antimony ore. The veinstones chiefly quartz, with much brown spar and often calc spar. The veins range *south and south-west.*

The third yields lead glance with one ounce of silver per quintal, much iron pyrites, a little black blende, and red iron ochre. Veinstones are quartz, sometimes with chlorite mixed and surrounded with clay. The veins range *north and south.*

The fourth yields lead glance with one-fourth to three-fourths of an ounce of silver per quintal, radiated pyrites, and sometimes brown

blende. The veinstones are heavy spar, fluor spar, a little quartz, and rarely calc spar. The veins range *east and west.* To this system Werner boldly referred the veins of Derbyshire, the Harz, and also those of Gisloff in Scania!

The fifth consist of native silver, silver glance, and glance cobalt, sometimes with grey copper ore, lead glance rich in silver, fine-grained brown blende, and sparry ironstone. The veinstone is heavy spar in a state of disintegration, and fluor spar. It always occurs in the *intersections* of the first and fourth systems. Its directions are north and south, and east and west. It sometimes is found even in the middle of the westerly veins.

The sixth contains native arsenic and light red silver ore; with a little orpiment, copper nickel, glance cobalt, native silver, lead glance, iron pyrites, and sparry ironstone. The veinstones are heavy spar, green fluor spar, calc spar, and a little brown spar. This system occurs in the intersections of the fourth and fifth systems, or in the middle of veins.

The seventh is of red ironstone, with a little iron glance, quartz, and heavy spar. Occurs in the *upper parts* of veins.

The eighth and newest is of copper pyrites, mountain green, malachite, and red and brown iron ochre, with a little quartz and fluor spar.

Relation of Mineral Veins to the Local Centres of Igneous Action.

Our investigations lead directly to the inquiry, how far the geographical occurrence of metalliferous veins is connected, as that of rock dykes is known to be, with the evolution of igneous rocks?

Evidence on this subject can be obtained in two ways: first, by comparing metalliferous and non-metalliferous districts of old strata in their geographical relation to igneous rocks and convulsions; secondly, by examining the relation to igneous agency of the locally metalliferous newer strata.

In Older Rocks.—The older rocks are not by any means universally stored with metalliferous veins any more than with dykes. Large tracts in the slate rocks of Devonshire are nearly devoid of metals, but near the granitic masses of Cornwall they are abundantly supplied with veins. In Wales the slate rocks yield copper and lead chiefly along the western borders of the Principality, where the local centres and axes of elevation are situated. Amid the Cumbrian lakes lead and copper veins adjoin the granitic, hypersthenic, and syenitic axes of Carrock, Skiddaw, High Pike, &c. They occur near the porphyries of Helvellyn and Old Man, but the greater portion of the slates, far removed from the foci of disturbance, are devoid of mineral treasures.[1]

In Scotland metallic veins adjoin the granitic nucleus of Strontian.

The Mining tracts of the Harz, the Erzgebirge, Hungary, Brittany, and other localities are convulsed by disruption and diversified

[1] See Postlethwaite.

by the intrusion of granitic and porphyritic rocks; the Ardennes mountains, which yield few veins, develop hardly any igneous rocks.

The carboniferous limestone tracts of Mendip, Derbyshire, and Flintshire, of Wharfdale, Swaledale, and Alston Moor, have been shaken to pieces by many convulsions, and they are very rich in lead and zinc; but the greater part of the Yorkshire and Northumberland limestones, affected by only one or a few general elevations, are poor in metal.

In Newer Rocks.—The newer rocks are metalliferous only in the vicinity of the foci of their disturbance, as round the central granite of France, near the igneous masses of the Pyrenees and the Alps; in all which places the metallic ores are so related to the igneous rocks that they occur only in a narrow zone at the junction of the igneous and the altered stratified rocks.[1]

Conclusions on this Subject.—We must not shut our eyes to some decided differences between the situations of dykes and veins. For instance, the Island of Arran is traversed by hundreds of dykes of basalt, porphyry, and pitchstone, but metallic veins are almost unknown there. Alston Moor is dissected like a map by veins of lead ore, but very few whin dykes occur there; on the contrary, in Northumberland and Durham whin dykes abound in the coal tracts where lead is hardly known. It is, besides, too remarkable a thing to be overlooked, that south of Durham barely a solitary whin dyke or porphyry dyke is known through the metalliferous tracts of Yorkshire, Derbyshire, Somersetshire, and Flintshire. This contrast is the more remarkable in the country about the sources of the Tyne and Tees, because there basalt has been erupted in vast quantity, and at its eastern termination appears related to several dykes of great extent. This mass of basalt is traversed by the veins in the same manner as the limestone is, and we may accept the conclusion that both are due to heat, but that the vein marks a later or collateral stage, in which there was less heat and more water, acting more slowly.

Mining.—At the present day we find in California and Australia the very same modes of working alluvial deposits which were practised in Gallicia for gold, and the Cassiterides for tin in the days of Pliny and Strabo and Herodotus,[2] and perhaps in equally ancient times in those hyperborean regions, the Ural mountains, which still furnish so much gold to Europe. Probably many great mountain chains, full of quartzose and metamorphic rocks, yielded gold in the earlier ages of the world; though none of the rivers washed it out in such abundance as the streams of Lydia. Not much of the gold and silver of the ancient world was obtained by mines properly so called, at least in Europe, till the heroic spirit was replaced by great commercial activity. Then the Athenians dug silver ores from Laurion, the Carthagenians and Romans obtained silver and gold

[1] Observations of Dufrenoy, Von Buch, &c.

[2] Hist. Nat., many notices.

from Spain; the Romans separated silver from the lead ores of Derbyshire and the north of England. Peculiar mining customs, not yet extinct in Derbyshire and Cornwall, bear testimony to the high antiquity and foreign source of the art of mining, as established in these countries; while throughout the North of England such terms as groove, and sump, and toadstone [1] betray the later influence of German workmen.

As in all other departments of geology, practical knowledge of the phenomena discussed must be gained by examination of the structure of some of the districts which have been mentioned. Many public museums, especially that of the Royal School of Mines, contain examples of the modes of occurrence of the several ores, models of lodes, and illustrations of various facts connected with mining districts, by studying which a useful preliminary practical knowledge may be gained, which will facilitate practical work in the field and underground. The Jermyn Street Museum also contains a valuable collection of models of mining appliances.

The art of the miner, founded on long experience, is now gradually acquiring the aspect of applied science. To bring it fairly within the circle of inductive philosophy—to give it more exact laws, based on a surer classification of phenomena—is an object of the highest import for humanity. On the command which man has acquired over the various properties of metallic matter has depended much of his civilisation and a large part of his power over the forces of nature. As this command is extended, these forces may be still more completely brought within the direction of the human mind. To do this, science must be carried into the mines, and miners brought into the classrooms of the professors of chemistry, geology, mineralogy, and mechanics. Practice thus becomes method, and experience is exalted to theory.

[1] *Groove* is scarcely altered German for *a mine; sump*, a shaft below level, is clearly from *sumpfen*, a German verb *to sink; toadstone*, in which the metallic vein is unfruitful, is *todstein*, German for dead or *unproductive rock.*

CHAPTER XXIII.

THE CHIEF MINERAL DEPOSITS IN BRITAIN.

Gold.

Gold is always native, always alloyed with silver, and contains minute quantities of copper and iron. Iron pyrites almost always contains gold. Gold usually occurs in quartz veins, which are sometimes in granite, and sometimes in schists and the older primary rocks. Much gold has been obtained from the eastern slope of the Ural, a little from the western slope, and from the Siberian governments of Tomsk, Yenisseisk, and Irkutsk. The veins at Beresow are in granite. The Austrian gold mines are on the western borders of Transylvania at Zalathna, where the gold is combined with tellurium. At Schemnitz and Kremnitz, gold is obtained from silver. The sands of the Rhine between Bâle and Mannheim, especially about Strassbourg, have long yielded gold. In France the river Arriège derives its name from "Aurigera." French gold is chiefly obtained from lead veins. The only quartz vein in France worked for gold is that of La Gardette in the department of Isère. The sands of the Douro and Tagus have both been washed for gold, but at the present day the only auriferous streams in the peninsula are the rivers Sil and Salor. Auriferous pyrites is found in the Auzasca valley near Monte Rosa; and gold is worked in the Serpentine near Genoa.[1]

Gold in Wales.—The British gold mines were formerly of some importance. The Romans worked a gold mine at Gogofaw, west of Llandovery, in South Wales, where gold occurs in a quartz vein, cutting the Arenig rocks. A more important gold region lies on the north side of the river Mowddach, in Merionethshire; and from 1854 to 1866, 12,800 ounces of gold were obtained in this region, chiefly from the Vigra and Clogau mines. The auriferous veins run east and west, and the gold was most abundant, in quartz, at the points where the veins cross other mineral lodes, especially those containing ores of silver, copper, and lead. Welsh gold is of a pale colour, owing to its being alloyed with silver; and this circumstance somewhat reduces the value of the metal.

[1] Concerning the distribution of gold and other metals, reference may be made to Whitney, "Mineral Wealth of the United States;" and John Arthur Phillips on Ore Deposits.

In Scotland[1] gold has been found in no inconsiderable quantity among the hills of Dumfriesshire, where gold-mining employed hundreds of men in the reign of James V. of Scotland, and yielded a large amount of metal. And among the metamorphic rocks of Sutherland gold occurs, and has been from time to time successfully worked by washing the superficial gravels.

In Ireland.—In county Wicklow gold is well known to occur; and at one time, in 1795-96, the Balin Valley brook, a tributary of the Ovoca, yielded about £14,000 worth of gold. All the mines were *shallow placer* mines less than 50 feet deep.

Silver.—A considerable vein of silver was found at Hilderston in Linlithgow; and in 1715 a valuable silver vein was worked in the Ochills, between Middlehill and Woodhill.

There is now no silver mine in Britain, but a large amount of silver is obtained from lead mines. Some of these occur in the Llandeilo rocks, and some in the Carboniferous limestone. The highest yield of silver is from the great Laxey mine, in the Isle of Man. Other important silver lead mines occur in Cornwall, Devonshire, Cardigan, Montgomery, Shropshire, Westmoreland, Yorkshire, Durham, and Northumberland.

Copper.

British Copper Mines.—The greater number of copper mines are in Cornwall. The copper mostly occurs in lodes, which run within twenty-five degrees of due east and west. Other lodes run from north-east to south-west, and from north-west to south-east. The productive strip of country stretches along the course of the granite masses, forming a belt about fifteen miles wide, between Dartmoor and the Scilly Isles. On the south-east of the granite of St. Austell are the Fowey copper mines, and round Redruth and Penrhyn there is abundance of copper ore. Many mines contain copper ore in the upper part and tin ores below. The copper ores traverse both the granite and overlying slates. The prevailing ores of Cornwall are the bi-sulphide and sulphide of copper, together with some amount of red oxide, carbonates, and silicates. Arsenical pyrites abound in the Tavistock district of Devonshire. In Cheshire, at Alderly Edge, copper occurs in the Lower Keuper Sandstone as blue and green carbonates. A similar deposit, also exhausted, occurs at Gardiston, near West Felton in Shropshire.

[1] Native gold attracted attention in Scotland at an early period. In 1153 David I. granted to the Abbey of Dunfermline a tythe of all the gold he should obtain from Fife and Forthrif. The Scotch Parliament in 1424 granted the crown all the gold mines in Scotland. Those of Crawford Moor were discovered in the reign of James IV.; and in the reign of James V. much of the gold coinage was minted from native gold. For a long period the mines were worked by Germans and Dutchmen. About 1578 gold was found abundantly in Henderland Moor in Ettrick Forest, and from time to time a little has been met with down to recent years.[2]

[2] "Early Records relating to Mining in Scotland," by R. W. Cochrane-Patrick of Woodside, 1878.

The carboniferous limestone of the Parys mountain in Anglesea has long been productive of copper; and other mines in this formation have been worked at Slanymyneck Hill in Shropshire, near the Great Ormes Head, near Hartington, on the borders of Staffordshire and Derbyshire; while there is an accumulation of bog copper on the west of Rhobell-fawr, near Dolgelly. Lodes of sulphide and blue and green carbonate occur in the neighbourhood of Snowdon, Beth-gelert, and Moel Hebog. The lead mines near Aberystwith are charged with copper. In Ireland important mines occur in Avoca in Wicklow. Copper pyrites is the chief British ore.

The Coniston copper mines of Cumberland are in Cambrian rocks. They are principally copper pyrites found in quartz lodes running east and west.[1] Similar deposits are found in Wicklow, and it is in rocks of similar age that we find the native copper of Lake Superior, and the Rio Tinto district in the south-west of Spain. The Devonian rocks are nowhere richer in copper than in Cornwall and Devonshire.

In many of the Cornish mines the copper pyrites is associated with iron pyrites, and about Redruth copper succeeds tin in the deeper part of the lode. In the west of Cornwall the grey sulphide is associated with specular iron ore.

Foreign Copper Mines.—Copper is widely distributed in Europe, chiefly in the Primary rocks. The Kupferschiefer of Thuringia is worked as an ore of copper about Mansfeld in Prussia, where the rock yields fifty pounds of copper to the ton. The Permian strata of Russia are also copper-bearing, especially between Perm and Kazan. The richer mines near Katherineburg are on the east side of the Ural, and consist of lodes of copper pyrites with malachite in the upper part. At Chessy near Lyons, the blue carbonate of copper was formerly obtained from the base of the Permian sandstone. The principal Italian copper ore is the sulphide found at several places in Tuscany, in serpentine and gabbro; but the greatest copper-producing districts of the world are in Chili between the 25th and 30th parallels, where the ore is found in volcanic rocks of Cretaceous age.[2]

Tin.

Daubrée's Views on the Origin of Tin.—Tin veins differ from those of other metals in the ore being an oxide; the gangue consists of quartz, the tin is diffused in the quartz, and associated with wolfram and arsenical pyrites, besides which there occur various silicates, fluorides, and borates, including lepidolite, topaz, pycnite, tourmaline, and axinite. Apatite, a phospho-fluoride of lime, is common, and accompanied by other phosphates. All over the world there is the same association of tin with silica, fluor, boron, phosphorus, and arsenic. M. Daubrée urges that fluorine has been the chief agent, not only in forming these minerals, but in bringing the tin to the positions in which it is found.

[1] See Postlethwaite: "Mines and Mining in the Lake District," 1877.

[2] For many facts relating to Copper we are indebted to H. Bauerman, F.G.S.

Fluoride of tin at high temperatures is a stable compound, and may have been brought up from great depths in this combination. Oxide of tin is always associated with tourmaline, the existence of which is assumed to be connected with a volatile fluoride of boron. In fact, all the minerals would originally have been fluorides, and have gradually acquired their present combinations. Oxide of tin occurs in the crystalline form of felspar, which is sometimes also replaced by tourmaline. Oxide of tin has been formed experimentally by Daubrée, by heating together perchloride of tin and steam, as well as by dissolving the perchloride of tin in a current of dry carbonic acid.

Rutile is similarly obtained artificially by heating together steam and the perchloride of titanium, from which it is inferred that titanic acid has resulted from the decomposition of fluoride of titanium, which is associated with the fluoride and chloride of phosphorus and boron. On such a view the ores would be comparable to deposits formed around volcanic vents.

Apatite is produced by passing a current of perchloride of phosphorus over caustic lime heated to redness, when the perchloride is absorbed and decomposed. In a like manner, topaz is formed by the action of fluoride of silica on pure alumina; and corundum has been obtained by the action of volatile metallic fluorides reacting on oxides.[1] Such an interpretation has the merit of accounting for the minerals associated with tin.

Tin Lode at Redruth.—Around the granite hill of Carn Brae, about a mile south-west of Redruth, are many famous tin mines connected with the Great Flat Lode. The lode in the eastern part of the Wheal Uny strikes a little north of west, and being only inclined 46° south, is much flatter than most of the tin veins in Cornwall, which have an average inclination of 70°. The leader varies from eighteen inches wide to two inches wide. Its walls have a smooth slickenside character. The lode which lies on the under side of the leader is a compact schorl rock with veins of quartz, cassiterite, chlorite, and iron pyrites. On the upper side of the leader the capel is compact schorl rock. The greyback or black granite is not separated by any line of demarcation from the lode, and the capel is similarly inseparable from the killas. Though this is the section at the 130 fathoms level, it varies a good deal as to the relations of lode to the leader. At a greater depth (175 fathoms) the leader becomes a copper lode two to four feet wide. In some of the other mines the leader becomes a quartz vein. The lode where it contains tin is a mass of schorl rock from four to fifteen feet wide, and one to three per cent. of cassiterite distributed in little grains or strings. The capel is also a schorl rock poor in tin ore, with its constituent minerals arranged in layers, thus indicating, and by its graduation into the adjacent rocks, that the lode itself is only a more altered portion of the granite or killas in which it occurs. Killas is frequently altered into schorl rock, sometimes becoming tourmaline

[1] Daubrée, "Géologie Expérimentale," Première partie, 1879.

schist and sometimes capel; hence the Great Flat Lode, being a band of altered rock, is different from a vein as commonly understood, and might be termed a tabular stock work. This deposit yields more than one-eighth of the tin ore of Cornwall.[1]

Tin near Helston.—Close to the turnpike road leading from Penryn to Helston, and about four miles from the latter town, are the tin deposits of the East Wheal Lovell. These lodes are usually very narrow, sometimes only a couple of inches thick; but in places rich deposits of tin occur on both sides of the vein. There is a leader or little vein of quartz, less than half an inch thick, running through the granite, and on each side of it a quantity of tin stuff which is a mixture of quartz, mica, cassiterite, pyrites, and other minerals. There is no wall separating the tinny mass from the granite. Sometimes the tin was more developed on one side of the leader than on the other. The main mass of the East Wheal Lovell extends like a pipe from the forty fathom level to the 110 fathom level. Dr. Foster remarks that there are other pipes and bunches of tin ore, similar to those which occur in the St. Ives district; but they differ in the absence of the mineral tourmaline. Concerning their origin he observes that the leader was evidently an open fissure, so that after the solidification of the granite, cracks were formed in it through which vapours or solutions ascended, decomposed the felspar, and deposited tin stone and other minerals among the constituents of the granite.[2]

Tin Lode of St. Columb.—Another important locality for tin is Park of Mines, three miles south of St. Columb. The nearest granite is a portion of the great mass north of St. Austell, which approaches within three quarters of a mile. Many little veins run from north to south through the clay slate, varying in thickness up to a quarter of an inch. They occasionally enlarge to one or two inches and contain cassiterite. Near these insignificant little strings, lenticular masses of tin stone occur in the planes of bedding of the clay slate. They are termed the east-and-west lodes, but correspond to the deposits which when horizontal are termed floors in Cornwall, and flats in the north of England. The only minerals associated with the cassiterite are schorl, quartz, and kaolin. The clay slate near the boundary of the tin layers is usually stained red by oxide of iron.[3]

Tin of St. Agnes.—In the St. Agnes district, Dr. Le Neve Foster has described several tin lodes. One of these, known as the Pink lode in the Penhalls Mine, east of Trevaunance Cove, extends thirty-five degrees north of west in the clay slate. The leader consists of quartz, cassiterite, chlorite, iron pyrites, and pieces of capel, and has a width of from four to fifteen inches. The rock on each side is termed capel, when by the infiltration of mineral solutions it is changed from a soft slaty rock to a compact mass of quartz

[1] Dr. Le Neve Foster, Q. J. G. S., vol. xxxiv. p. 640.
[2] Trans. Roy. Geol. Soc. Cornwall, vol. ix. part II., 1876.
[3] Foster, Miners' Association of Cornwall and Devon Report, 1875.

and schorl, arranged in the original bedding of the killas with veins of quartz, and intersected with strings of cassiterite and chlorite.

The capel is usually on both sides of the leader, but sometimes on one side only. It is never more than two feet thick. The deposit of tin ore appears to have been subsequent to the formation of the capel. The Wheal Kitty is a similar mine. The Wheal Coates is especially interesting as yielding pseudomorphs of cassiterite after orthoclase, showing how the metallic matter has replaced the felspar. The Cligga promontory consists of granite intersected by more or less parallel metallic veins running 20° to 30° north of east. Veins of quartz run through the granite, and on each side of the quartz is a band of greisen which consists of quartz and mica, though it often contains schorl, gilbertite, and a little tin stone. There is no plane of separation between the greisen and the granite as there is between the greisen and the quartz. The cliff is intersected with a countless number of little veins, which stand out because the greisen is more durable than the granite.[1]

The Wheal Mary Ann.—The lode at Wheal Mary Ann runs a few degrees east of true north through the killas. In one working the killas is lined with cab, which is a sort of chalcedony; next succeeds crystallised quartz of the ordinary kind, which is lined with galena ; and, finally, the centre is occupied by chalybite or spathose iron. Sometimes the cab contains fragments of killas and galena, while vitreous quartz fills up the centre part of the lode. Elsewhere the cab on the eastern wall is traversed by crystallised quartz, then succeeds a band of vitreous quartz, and, finally, on the foot wall a breccia of killas and cab cemented with galena and calc spar. This condition of the lode is explained by Dr. Foster, who supposes the formation of the fissure as a slight fault, in the cavities of which the cab was deposited, cementing the fragments of the rock into a breccia on the foot walls. After this the fissure was reopened, the new fracture sometimes passing along the middle of the cab and sometimes cutting across it, and then quartz, galena, chalybite, and calc spar were successively deposited in the open spaces.[2]

Stockworks near Bodmin. — The term stockwork has been adopted from the German, to designate large masses of rock impregnated with metallic ores, or intersected with mineral veins which cross each other in all directions, or at short distances apart. The tin stockworks of Cornwall occur in the clay slate, granite, and elvans.

Such mines are found at Wheal Prosper, near Bodmin, where a distance of 800 yards of killas, thirty yards wide, is crossed by multitudes of little veins, rarely more than one-eighth of an inch thick, and it only contains three pounds of ore to the ton of rock. The Mulberry mine in the same neighbourhood exhibits similar pheno-

[1] "Remarks on some Tin Lodes in the St. Agnes District," Le Neve Foster, Trans. Roy. Geol. Soc. Cornwall, vol. ix. part III., 1877.

[2] Le Neve Foster, "The Lode at Wheal Mary Ann," Trans. Roy. Geol. Soc. Cornwall, vol. ix. part I., 1875.

mena. At Carrigan in the north, in the Hensbarrow granite tin mines occur in the finest mass of greisen in Cornwall. Dr. Foster believes the greisen to be merely altered granite.[1]

Tin in New South Wales, &c.—The granite in New South Wales is regarded by Mr. Ulrich as forming a vast stockwork near the township of Inverell, and the quantity of tin lying on the surface in that district is estimated at twenty-five times the annual produce of Cornwall.

Immense quantities are obtained from Banca and Billiton.[2]

The mines of Chili and Peru also yield a large quantity of tin.

Lead.—Lead occurs in veins chiefly in the newer Primary rocks. Galena is the most abundant ore, but carbonate and phosphate of lead are both met with in some quantity.

In the Cambrian district of Shelve in Shropshire, towards the borders of Montgomeryshire, the lead mines have been worked at intervals since the time of the Romans. The mineral veins are almost entirely in the Arenig and Llandeilo rocks. In the north-west of Montgomeryshire mines also occur at Llangynog in Arenig and Llandeilo rocks. In the Llanidloes district the veins have a general east-and-west direction.

When the Carboniferous limestone appears in North Wales, in Flint and Denbigh, ores of lead are found between Flint, Holywell, and Llangollen. The general direction of the veins is east and west.

In Cardiganshire the lodes chiefly occur in anticlinal folds, the corresponding synclinal curves being usually barren. There are many mines on the south side of the estuary of the Dovey along the course of the Rheidol, between Plynlimmon and Lampeter, and on the east side of Plynlimmon. In this district the lodes range from E.N.E. to W.S.W. In Carnarvonshire the lead district lies between Capel Curig, Bettws-y-Coed, and Trefriw.

In Cornwall the most important are at West Chiverton, near Camelford, and near Laureath. Lead is limited to the eastern side of the county; the direction of the lode is east and west at West Chiverton. Herodsfoot mine, near Laureath, has the lode nearly north and south. The number of lead mines in Devonshire is small. They chiefly occur in the Ilfracombe slates, in the neighbourhood of Combe Martin, and at Frank mills, near Exeter. In the North of England, Cumberland, Northumberland, Durham, and Westmoreland, all yield large quantities of lead. The mines at Alston Moor belong to the governors of Greenwich Hospital; the Weardale mines belong to the Ecclesiastical Commissioners; but among the more interesting are those of Allen Dale, which belong to the family of Mr. W. B. Beaumont. Nearly all these mines occur along the line of the Carboniferous limestone of the Pennine chain, in the portion which lies above the Great Whin Sill. In Swaledale, in Yorkshire, the ore chiefly occurs in the Main limestone, and extends over an area fifteen miles long by six broad,

[1] Le Neve Foster, "Tin Stockworks in Cornwall," Q. J. G. S., vol. xxxiv., p. 654.

[2] Reyer, Banka.

between Wensleydale on the south and Teesdale on the north; the lodes all run east and west, though in the south-east of the district there are a few lodes which run from north-east to south-west. South of the Swale, the ore frequently lies in caverns in the limestone rather than in true lodes.

The lead veins in Alston Moor occur in fissures, where the strata are sometimes dislocated 200 feet. On the downthrow side of the fault the limestone is compact with scarcely a parting; on the upthrow side, the limestone is broken up with joints, often filled with clay. The joints are most numerous near to the surface; most numerous in limestones, and least numerous in shales. The veins are grouped by Mr. Wallace into three kinds. The first run between N. 60° E. and S. 60° E. The second class includes the veins running north and south. Both these classes of veins are intersected by small veins, some of which run S. 55° E. and others S. 55° W. magnetic. These veins contain lead above, and lead and copper below. The great sulphur vein, as it is termed, is not less than 300 feet wide at Crossgill. It is filled with quartz and iron pyrites, and has the aspect of being formed by a great number of parallel fissures. It runs from N.W. to S.E. At Cashburn it consists of quartz, and forms low round hills; it is supposed to be posterior in date to the cross veins of Alston Moor. It is parallel to a whin dyke. Among the east-and-west veins are the Browngill and Benty Field veins. The Benty Field ramifies into weak strings, but at Dryburn the strings unite and form a wide vein, which dislocates the strata 60 feet; and this is the character of many of the veins of this district, though the throw is usually much less. Next to the Browngill, Fletcheras vein is the strongest in this district. The cross veins are of all magnitudes—the Carrs vein has a dislocation of 260 feet, but the throw varies with the vein and is sometimes only a few inches. The contents of the cross veins are generally softer and less compact than those of the E. and W. veins. It is held by Mr. Wallace that the cross veins were either anterior to or contemporary with the veins that run E. and W.

Lead ore is found mixed with quartz, carbonate and sulphate of lime, carbonate and sulphide of iron, fluor spar, baryta, &c. The richest deposits are in the upper part of the mountain limestone; but in the lower part of the mountain limestone, which is traversed by augite andesites, there is very little lead ore. The deposits of lead ore in the veins are generally divided from each other in this district by shale. The Rampgill vein is uniformly wide, and well filled with vein minerals.[1]

The mining district of Derbyshire lies between Buxton and Castleton on the north, and Cromford and Wirksworth on the south. It is about thirty miles long by twelve miles broad, and is most productive on the eastern side. In this district the richest deposits occur when the strata form synclinal folds.

[1] Wallace on Lead Deposits of Alston Moor.

Mr. J. D. Kendall urges that the veinstones of all the veins in Cumberland are part of the original rock in which the metallic matter has been deposited[1] from chemical solutions, which removed the soluble rock-substance along a joint, and filled the spaces with ores.

In the Isle of Man there are eleven lead mines, the most famous of which is the Great Laxey. Galena yields from 60 to 75 per cent. of metallic lead. The quantity of silver in the lead varies at different times in the same mine; 12 ounces to the ton is common, and 35 ounces of silver to the ton of galena is exceptional.

In Scotland the Leadhill mines in Lanarkshire were formerly among the most important; and in Ireland an important lead mine occurs at Luganure, in County Wicklow.

Zinc is obtained from lodes, some of which occur in the older Cambrian rocks, others in the Carboniferous limestone. The mines which yield the largest quantity of zinc, also yield ores of lead. Thus the West Chiverton in Cornwall, the Van mines of Montgomeryshire, and the Great Laxey of the Isle of Man, are among the most important; but the Minera in Denbighshire, the Talargoch in Flintshire, the Woodend mine near Threlkeld, and Force Crag mine, Cumberland, and other mines in Shropshire, Devonshire, Cardiganshire, Caernarvonshire, and Radnorshire, all have local importance. The chief ores are sulphide termed blende, carbonate termed calamine, and silicate of zinc. The production is decreasing. Blende yields 40 to 47 per cent. of metallic zinc.

Bismuth.—Native bismuth is found near Redruth in Cornwall, at Carrack Fell in Cumberland, and at Alloa near Stirling. The sulphide of bismuth is also met with in Cumberland and Cornwall; and the oxide and carbonate are found at St. Agnes in Cornwall; but the supply of bismuth in our own country is too small for it to have any importance as an ore.

Of **Mercury** there is no British ore. Mr. J. A. Phillips remarks that the ores are found in the most ancient as well as in the most modern rocks. Some of the principal veins are in the Silurian strata, while the deposits of New Almaden, in California, are of Cretaceous age.

Arsenic is obtained from the ores of tin in Cornwall and Devon.

Antimony.—A little sulphide of antimony is found in Cornwall, but the chief supply is from Borneo.

Nickel occurs in small quantity in this country, chiefly in the Pengelley and St. Austell Consol's mines in Cornwall, and at the Bathgate silver mine in Scotland. Nickel is found associated with iron at Voel Hiradig, Cwm in Flintshire, to the amount of about 2·3 per cent.

Cobalt, in the form of cobalt glance, is found in the Botallack mine; and smaltine and cobalt bloom are also found in Cornwall.

[1] Manch. Geol. Soc., April 1884.

Distribution of the Chief Iron Ores in Britain.

Locality.	Kind of Ore.
	In Primary Rocks.
Cornwall at Restormel, near Lostwithiel	Hematite and Göthite ; and iron pyrites.
Devonshire	Hematite and magnetite, at Brixham and Haytor mine.
Somersetshire	Hematite and chalybite, in Brendon and Mendip Hills.
Cumberland and North Lancashire	Hematite, limonite, and chalybite, in Carboniferous limestone.
Northumberland, Durham, South Yorkshire, Derbyshire, Staffordshire, Shropshire, Warwickshire, North Wales, South Wales, Monmouthshire	Clay ironstone or chalybite, chiefly in the coal measures.
Gloucestershire	Limonite in Forest of Dean coal-field.
Scotland	Clay ironstone.
Ireland	Clay ironstone.
	In Secondary Rocks.
Lincolnshire	Lower lias.
North Yorkshire	Middle lias, &c., of Cleveland district.
Oxfordshire	Lias (Vale of Evenlode and Vale of Cherwell), Inferior Oolite (at Stow-nine-churches) ; the Neocomian sands of Shotover Hill are not worked.
Northamptonshire	Inferior Oolite.
Wealden district	Wealden.
Wiltshire	Coralline Oolite, oolitic ore at Westbury.
Lincolnshire	Neocomian oolitic ore at Seend in Wilts ; Tealby, &c.
	In Tertiary Rocks.
Ireland	Aluminous hematite of Antrim.

Iron.—Iron ores in Britain are widely distributed in the Carboniferous and Secondary strata. In the Carboniferous limestone they chiefly occur in the form of red oxide or hematite, which is extensively worked in the district of Furness and about Cleator Moor in Cumberland. But in Somerset in the Brendon Hills, and in Devonshire on the eastern borders of Dartmoor, and in Cornwall near Lostwithiel and Wadebridge, there are important mines of red or brown hematite. In the coal measures, the iron ores are regularly interstratified, and form what are known as clay iron ore, which is a carbonate of iron. Important beds are the black band ironstone of Staffordshire, Lancashire, and Scotland, which lie near the top of the upper coal measures. Ironstone beds also occur below the thick coal of South Staffordshire, and on the same horizon in Warwick and North Wales.

The South Wales iron is chiefly in the Gannister beds. In the Cleveland district of Yorkshire, extending south of the river Tees, the middle lias contains important beds of clay ironstone.

In the north-west of Lincolnshire, a similar ironstone occurs in the lower part of the lower Lias; and in Northamptonshire the Northampton sands, corresponding to the lower part of the inferior oolite, have yielded rich deposits of iron ore about Wellingborough, Crauford, and Woodford.

Iron in Cornwall.—Most of the iron in Cornwall occurs between Padstow on the north and the neighbourhood of St. Austell on the south. Among the more important of these lodes are the Pawton mines near Padstow. The ore is partly red hematite mixed with limonite and spathose carbonate. The Perran lode has similar ore, but has a direction 35° north of west.

Many other localities in Cornwall are known to yield good ores of iron, and among the more important are Boscarne, west of Bodmin; Tregorne, west of Mulberry Hill, and the neighbourhood of Grampound, where magnetic ore occurs.

The iron lodes of Cornwall mostly run to the west of north, and contain hematite or limonite. An important mine occurs at Lostwithiel, and extends for 1¾ miles; the ore is chiefly the hydrous oxide termed Gœthite. Near to the surface the carbonate of iron is altered into limonite. The ore yields thirty to fifty per cent. of metal.

Iron in Devonshire.—The Haytor iron mines on the eastern border of Dartmoor are an example of the occurrence of thick beds of magnetite, interstratified with altered shales and sandstones of Carboniferous age. The rock near the iron ore is always charged with hornblende, and sometimes almost made up of actinolite.

The beds of iron ore are, according to Dr. Le Neve Foster, ten feet, fourteen feet, and six feet thick in three of the four beds. The strike of the beds is south-east. The iron ore is thought to have been originally in a condition like that of Cleveland ore, and to have been subsequently altered into magnetite. Near the surface the magnetite is converted into ochre by atmospheric decomposition. Actinolite and garnets almost invariably accompany deposits of magnetite.[1]

Magnetite iron ore worked at Haytor, near Islington, is a compact black granular substance. Iron ore occurs at Smallacombe in the form of limonite. Other lodes of brown hematite are found at Hennock, Buckfastleigh, and North Moulton. At the Frank Mills lead mine the lead ore is succeeded by carbonate of iron containing a large amount of manganese.

Red hematite and limonite are found in the Plymouth limestone, near Brixham; the ore is mostly compact, and includes some kidney ore; on analysis it yields from forty-four to sixty-three per cent. of metal.

Somersetshire Iron Ores.—In Somersetshire iron ores occur at

[1] Dr. Le Neve Foster on Haytor Iron Mine, Q. J. G. S., vol. xxxi. p. 28.

Eisen hill, and in the Brendon hills. The ore is partly carbonate of iron, rich in manganese and partly brown oxide. These ores are found in the Morte slates which belong to the middle of the Devonian rocks. The ore chiefly occurs in veins and pockets. The produce is about thirty-four per cent. of metallic iron, and nine to ten per cent. of manganese. Hematite iron ores are also worked at Yatton, Windford, and in the Mendip Hills.

On Exmoor iron ores are found near Combe Martin, and in the Valley of the Exe, and north-east of Simon's Bath. It is usually a brown oxide. Some of the lodes are from nine to twenty-five feet thick.

Iron Ores in the North of England. — The iron ores of the North of England are chiefly obtained from the Carboniferous limestones of Weardale, Alston Moor, Haydon Bridge, Whitehaven, and Ulverstone. They consist partly of carbonate of iron and partly of hematite. The clay ironstone or argillaceous carbonate is contained in some of the bands of shale in a similar way to the ores of the coal measures. This ore is sometimes known as ballstones. Brown iron ore sometimes forms regular layers in the rocks round Alston Moor, and sometimes the brown iron ore occurs in the lead veins of Alston Moor, instead of fluor spar and quartz. Thus the lode of Rodderup Fell, where it crosses the valley of the Tyne, is a vein of brown iron ore sixteen to twenty feet thick, and similar veins occur in other parts of the same district. The carbonate of iron or sparry ore also appears abundantly in the lead veins, and is termed the rider or vein stone; and near Weardale, about Stanhope, the veins are so "ridered" with this ore in interlacing strings, that the rock has been absolutely carried away. The brown peroxide of iron is frequently mixed with the sparry ore; its existence is attributed to the decomposition of the carbonate of iron.

This is the ore which is worked in Carinthia, Styria, and Siegen. The carbonate of iron frequently invests previously-formed crystals of fluor spar and galena. The hematite or sesqui-oxide of iron is chiefly worked at Whitehaven and Ulverstone.

Cumberland Hematite.—The Cumberland hematite deposits occur in granite, Skiddaw slate, the Borrowdale series, Coniston rocks, and Carboniferous strata. In the Eskdale granite, the principal workings are near the Boot and the King of Prussia. The direction of the vein is north and south. The ore occurs in bunches on each side of a leader. This deposit is usually earthy, and sometimes contains decomposed felspar. Hematite has only been worked in the Skiddaw slate near Knockmurton, on one of the hills near Ennerdale Lake. Some of the veins run north-west, others north-east, and are quite as irregular as at Eskdale.

In the Coniston limestone, hematite is found at Water Blean, near Millour. The ore is free from mixture with the associated rock, and occurs in veins from a few inches to nine feet thick. The most important deposits of the district are in the Carboniferous limestone, and these present several different forms, occurring some-

times in the manner of beds, and sometimes in the manner of veins, and occasionally occupying depressions on the surface of the limestone, immediately beneath the drift. Examples of the bed-like deposits occur at the top of the Carboniferous limestone, as at Frizington, at Winder Gill, and at Bigrigg. Sometimes the floor is uneven, sometimes the roof is uneven, and the floor is often nearly all silica, forming a substance called by the miner's "whirlstone."

Other limestone bands are similarly more or less replaced by hematite. The vein-like deposits are shown by Mr. Kendall's map to lie in lines of fault. Among these are the Salter Hall mines and the Eskelt mines. Of the superficial dish-like deposits, one of the most important occurs at Hodbarrow, and in Furness deposits of this kind are common. Some of the vein-deposits, like those of Salter Hall and the Cleator district, run north and south, while others, as at Bigrigg and Frizington, run east to west.[1]

The percentage of peroxide of iron varies with the percentage of silica, so that the ore is poorer as it is more siliceous. In the upper coal measures hematite is found at Millyeat, near Frizington. The formation of the ore is usually dated as prior to the Permian period, because hematite fragments occur in the lower Permian breccia.

Mr. E. W. Binney, F.R.S., described hematite as interstratified in the lower coal, and there is no doubt that occasionally coal plants are mineralised with hematite.

In Furness the chief ores are the hard compact purple blue ore, lined with kidney-like concretions and spar, similar to those which occur in the Whitehaven district. This ore specially occurs at Lindal Moor, where it is worked for a thousand yards in a direction running north-west to south-east, in a vein which varies from a few inches to over ninety yards in width. A similar deposit is worked at the Stank mines, and the Yarlside mines. One of the most characteristic features of the hematite deposits is the way in which they are interstratified with the surrounding limestone and shale; but this condition is always due to replacement of the limestone in the planes of bedding by iron ore. It is impossible to speak with any certainty concerning the source of this or other ores; but although the hypothesis of emanations of vapour and solutions of metallic matter from the deep-seated regions of the earth offer a simple explanation, it is probable that we may with more confidence attribute the iron deposits to the insoluble residue left, when limestones are denuded by solution, and attribute their occurrence in veins to infiltration from above, slowly and during long periods of time. The chemical processes involved in making hematite out of carbonate of iron, are certainly consistent with the ordinary processes of denundation.[2]

Veins of ironstone in the Carboniferous limestone of South Wales extend from near Pontypool to Lydstep Point in Pembroke-

[1] J. D. Kendall, "Hematite in the Silurians," Q. J. G. S., vol. xxxii. p. 180.

[2] J. D. Kendall, "Hematite Deposits of Cumberland and of Furness," Proc. North of England Institute of Mining Engineers, vol. xxxi., 1882.

shire. They have long been worked in the Taff Valley, where the iron ore occurs in nearly vertical fissures.

Forest of Dean Iron Ores.—The iron ore of the Forest of Dean occurs in the Carboniferous limestone, and locally in the Millstone grit. It is brown hematite or limonite, and occurs in irregular cavities in the rock termed Churns. It is sometimes worked 750 feet below the surface. The iron ore deposits are about 100 yards below the coal measures. The ore varies in appearance from a close-grained black to a spongy black ore, or an earthy ore which on exposure becomes red. The richer ore yields 63 per cent. of metallic iron, the poorer ore about 23 per cent. Some other deposits occur in the Pennant sandstone at Frampton Cotterell, near Bristol, and many other localities in Gloucestershire.

Iron Ores in the Coal Measures.—In the coal measures the iron ore is the argillaceous carbonate of iron which occurs in grey, brownish, or black lumps and nodules, and is found in all the coal-bearing districts, though sometimes the quantity is too small for profitable commercial extraction.

In the Northumberland and Durham district, on the western side of the coal-field at Consett and Tow Law, the ironstone is in close proximity to the coal. The lowest seam is four to six feet thick.

In the Yorkshire Coal Field the clay ironstone is largely worked in the Bradford district, where some of the best iron in Britain is made. The South Yorkshire ironworks extend from Leeds by Barnsley to Sheffield and Rotherham. The best beds of ironstone intervene between the Barnsley Thick Coal and the Silkstone, ranging through about a thousand feet of the coal measures. The line is traced southward in Derbyshire, from the valley of the Don to the extreme south of the coal measures, but the bands of nodules are more irregular than in Yorkshire.

In Derbyshire the ironstones occur on the same horizon as in Yorkshire, between the Barnsley coal which is known as the Top Hard, and the Silkstone, called the Black Shale. The bands which contain the ironstone nodules are known as *rakes*, the more important of which are the cement rake of Alfreton, the pinder park rake of Staveley, the brown rake of Butterley, the black rake, the dogtooth rake at Staveley, the nodule rake, and the black shale rake, and the striped rake. These beds have a total thickness of 1600 feet. The coal and ironstone together are about 400 feet thick. The dogtooth rake at Chesterfield is an important mine, in which some of the beds are made up of the shells of the bivalve genus Anthracosia. In the Lancashire coal-field clay ironstone occurs, but the beds are thin and of little value.[1]

A little ironstone is raised in Nottinghamshire, and in Warwickshire. Excellent clay ironstone is found in the Bedworth district near Coventry.

In Shropshire there are many beds of ironstone, distinguished by local names, such as Chance Pennystone, Blackstone, Yellowstone,

[1] "Iron Ores of Great Britain," Part i., W. W. Smythe, 1856.

Blue Flats, White Flats, Pennystone and Black Flats. The ore yields about 35 to 38 per cent. of metallic iron, the nodules are usually brownish grey, often have a septarian structure filled with crystals of sulphate of baryta. Occasionally the iron contains minute traces of other metals. It is chiefly worked at Lillieshall, Madeley Court, and Madeley Wood, Ketley, Wombridge, and Packmoor.

In North Staffordshire the chief ironstone bands are the Red Shag, which has a reddish-brown fracture, and occurs at Hanley and Newcastle, the Gatter Mine at Hanley, the Red Mine, Cannel Mine, Pennystone, and Deep Mine. The percentage of metallic iron varies from about 32 to 40 in the different beds.

In South Staffordshire Dudley is the centre of the iron manufacture, which covers an area of about 50 square miles. The district, commonly known as the Black Country, extends from Wolverhampton by Bloxwick to Walsall, from Walsall to Halesowen, to Stourbridge, and from Stourbridge to Wolverhampton. The district includes seven important towns and sixteen large villages. The quantity of ironstone is probably greater than is to be found in any similar area within the same vertical space. Professor Jukes enumerates fifteen principal bands, which vary from two or three feet to thirty or forty feet in thickness, though the ironstones usually occur in dark clay called clunch or clod, which forms much of the thickness of the bed. Thus the Gubbin and Balls ironstone is seven feet thick, but only contains two feet of ironstone divided by three beds of clod. The Balls have a septarian structure, the septa being lined with iron pyrites, and sometimes with galena and blende.[1]

North Wales.—Argillaceous iron ore occurs in the Ruabon coal-field at Trefechan in about six or seven bands. In Flintshire the iron is found in the Carboniferous limestone near the Talargoch lead-mine, and contains a little cobalt and nickel.

The South Wales iron ores were formerly mined on the outcrop by means of races or streams of water directed on the ore, and then the ironstone was converted into oxide of iron and smelted. The lower coal measures contain the bulk of the beds of iron ore and coal. They extend over the whole coal-field; the yield of iron is richest in the east, and in the west the beds are thicker and poorer. The beds are extremely numerous, but rarely of any great thickness. The bed known as the Three-quarter Balls in the eastern part of the basin is about three feet thick. The iron beds are well worked in the Ebbw valley.

Irish Carboniferous Iron Ore.—The Leinster coal-field in the south yields carbonate of iron, but most of the ironstone, which occurs in nodules and concretionary masses, is found in the northern district of Leitrim, Tyrone, and Antrim.

In County Wicklow Mr. Tichborne has described a vein of magnetic oxide near Kilbride, which is two to three miles long, and sometimes six feet wide. Limonite occurs in the mineral veins at Cronebane.

[1] Jukes, "Iron Ores of Great Britain," Part ii., Mem. Geol. Surv., 1858.

Oxides of iron more or less siliceous are found in the Cambrian rocks of Counties Longford and Cavan, but chiefly in the district between Granard and Carrick-on-Shannon.

Scotch Iron Ores.—In Scotland most of the iron ores occur in the coal measures of Ayrshire, Lanark, and the country between the Firths of Forth and Clyde. The seams of ironstone vary in thickness from a few inches to two feet, and are mostly blackband clay ironstone, which yields 30 to 40 per cent. of metal, and is similar to the ores of North Staffordshire. Iron oxide ores are worked in small quantity in Shetland, Aberdeen, at Auchencairn in Kirkcudbrightshire, at Garleton in Haddingtonshire, and Whytock and Muirkirk in Ayrshire. The hematite at Auchencairn is similar to the kidney ore of Whitehaven.

Permian Iron.

In the Permian beds iron ore occurs in hollows or basins, as at Mwyndy, near Llantrissant. Sir Henry De la Beche recorded the occurrence of hematite unconformably covering the coal measures near Llanharran, in Glamorganshire.

Liassic Iron Ores.

Cleveland Ironstone.—The Cleveland ironstone is well seen in the Yorkshire coast between Old Peak, south of Whitby, and Middlesborough-on-Tees. It extends in a basin with several minor undulations, descending below the sea-level north of Robin Hood's Bay, and reappearing at Kettleness, and between that place and Staithes another synclinal fold sinks the ironstone below the sea-level. The best section is to be seen at Boulby. The iron ore continues to rise in the cliff, till at Huntcliffe it retires from the coast. It is then followed inland by way of Arncliffe, extending through the whole of the Cleveland Hills, and turning south-east, it disappears under the oolites. Usually the several seams of ironstone are parted by shale. They are frequently oolitic, and contain *Pecten œquivalvis*, *Avicula cynipes*, and other Lias fossils.[1] They thicken towards the north and ultimately unite, so that in the Eston Hills the ironstone has an aggregate thickness of 18 feet. The thick beds, however, are not always the most valuable, for though the ore at Grosmont has a thickness of nearly 14 feet, only 6 feet 6 inches of it are worth extracting, the remainder being interstratified with seams of shale. The ore yields 30 per cent. of iron, and has much the aspect of a sandstone. Mr. Bewick believes that the ironstone covers an area of 420 square miles. He estimates the average yield of every acre at 20,000 tons, and the total supply of the district at 4,820,659,200 tons, an amount which would supply 200 blast furnaces for 680 years, and enable each to turn out 200 tons of pig iron in a week.[2]

[1] Mem. Geol. Surv., "Iron Ores of Great Britain," Part i., W. W. Smythe, 1856.
[2] Jos. Bewick, "Geol. Treatise on the District of Cleveland," 1861.

In Lincolnshire iron ore is worked in the Lower Lias, on a lower horizon than the Cleveland ironstone. The mining district lies between the Trent, Humber, and Ancholme. The ore is sometimes 27 feet thick. It is spread about the village of Scunthorpe. The yield is 27 or 28 per cent. of metal. Another band known as the Pecten ironstone is about 4 feet thick, and occurs in the Middle Lias.

In North Lincolnshire, Frodingham is the centre of the iron district. The ironstone is covered with drift sand.

In Oxfordshire the Marlstone has been worked for iron ore at Fawler, Aynho, and near Banbury and Woodstock. The ore is especially developed in the valley of the Cherwell. It varies from 10 to 15 feet in thickness, and abounds in the *Rhynchonella tetrahedra*. It is often dark olive green, and yields about 32 per cent of metal.

Above the Upper Lias is the magnetic ironstone known as the Dogger bed. In the Rosedale Abbey mines the band is 20 feet thick, and probably corresponds to the Northampton sand. This ore contains about 65 per cent. of oxide of iron, equal to 45 per cent. of metal.[1]

Iron Ores from the Oolites.

The Iron Ore of the Northampton Sand.—The Romans worked the Northampton sand of the Inferior Oolite near Oundle, and the Norman castle of Rockingham is said to have been built for the protection of the iron furnaces of Rockingham Forest. The works, long discontinued, were resumed about 1860. The ore at the surface is hydrated peroxide of iron, but when quarried at some depth, each block has a nucleus of compact impure carbonate of iron, blue or grey, while deeper still the entire mass is carbonate of iron. This mineral replaces the carbonate of lime of fossils, though the greater part of the ore is free from fossils. The ore occurs in lenticular patches at Holt, Desbro, and near Stamford. Sometimes it forms the whole thickness of the formation, sometimes it is entirely absent. It contains grains of quartz, which in some beds are invested with hydrated peroxide of iron. Certain beds have the whole mass made up of oolitic grains $\frac{1}{50}$ to $\frac{1}{100}$ inch in diameter. On analysis the ores give about 30 to 75 per cent. of sesquioxide of iron, or 60 to 80 per cent. of carbonate.[2]

Beds of ironstone from 4 to 18 feet thick or more occur in Northamptonshire, while at Cogenhoe and Woodford the thickness is 20 feet. The stone at Cogenhoe yields 42 per cent. of metallic iron. At Gayton near Blisworth the ironstone is 10 to 14 feet; at Easton, Neston, near Towcester, from 6 inches to 3 feet; near Northampton, 12 to 14 feet; at Daston, near Northampton, 16 feet. It is largely worked at Wellingborough, where it is upwards of 12 feet thick; and here the ore yields 53 per cent. of metallic iron.

[1] Meade, "Coal and Iron Industries," p. 368.
[2] Judd, Mem. Geol. Surv., "Geology of Rutland."

In former years ironstone was worked near Peterborough in the Blisworth clay.

Iron Ore in the Coralline Oolite.—At Westbury in Wiltshire an oolite iron ore occurs in the Upper Calcareous grit. It is about 15 feet thick, and extends by Warminster to the north of Devizes and through Steeple Ashton into Oxfordshire. The Westbury ore is known locally as *brown* and *green.* The former yields about 42 per cent. of iron, the latter 38 per cent.

At Abbotsbury oolitic iron ore is found in the upper part of the coral rag, but is not at present worked.

Wealden Iron Ore.

The iron ore of the Weald has played an important part in English history, having been a chief source of iron from the time of Henry III. down to the first quarter of this century, when the works ceased to be remunerative owing to the failure of fuel. The common ore is clay ironstone, which occurs in nodules and thin beds towards the bottom of the Wadhurst clay. Another bed of shelly calcareous ironstone, serving both for ore and flux, occurs a few feet above the Ashdown sand. The ore is termed "myne." It was worked as late as 1857–58 in the Ashdown Sand near Wadhurst, and the ore was then sent to Staffordshire to be smelted. It usually yields about 35 per cent. of iron, varying between 25 to 40 per cent. The Ashburnham iron was remarkable for its toughness; cannon were cast from it; it was forged into weapons of war; and most of the older ornamental ironwork of London exhibits evidence of its malleable quality. Iron ore is still worked in the Lower Wealden beds of the Lower Boulonnais; the ore is chiefly raised at Ferques and near Boulogne; it is there a hydrated peroxide, which yields 34 per cent. of iron.[1]

Neocomian Iron Ore.—A brown oolitic iron ore occurs in the Middle Neocomian at Tealby near Market-Rasen.

Occasionally ironstone has been extracted from the Upper Neocomian beds near Leighton-Buzzard in Bedfordshire, where it occurs in massive brown nodules.

At Seend in Wiltshire iron ore occurs in the Lower Greensand. It is quarried in open workings, similar to those at Westbury. It yields 45 per cent. of metallic iron, and is a hydrous brown oxide.

In many localities the Neocomian sands are rich in brown iron ore, but deficiency of fuel has rendered them of no commercial value.

Tertiary Iron Ores.

The Bagshot Sands at Hengistbury Head near Christchurch contain several bands of nodular ironstone. The ironstone masses are several feet in length, and have accumulated in great quantity on the

[1] Topley, Mem. Geol. Surv., "Geology of the Weald," 1875.

beach. This ore was formerly collected and smelted, but of late years the works have been suspended.

On the north-west coast of the Isle of Wight near Yarmouth a clay ironstone was formerly collected to the amount of several hundred tons a year.

Iron Ore of Antrim.—In County Antrim interstratified with the basalt are a number of ferruginous bands, which occur above each other like seams of coal. They are well seen in the cliffs near Down Hill, and usually consist of a ferruginous clay called "bole," with an underlying layer of lithomarge. The most important bed, which has been worked commercially, and is used in the Cumberland iron furnaces, is seen at Port-Moon, immediately under the lower tier of basaltic columns. It consists of pisolitic iron ore of brown or reddish colour; it contains a good deal of fossil wood replaced by limonite. The thickness of the bed is about two feet. Beneath the pisolite is six feet of bole, a yellowish red ochre containing nodules of basalt, and this rests upon twenty-five feet of lithomarge. The pisolitic ore yields from 40 to 60 per cent. of metallic iron. The bole contains about half this amount of iron, while in the lithomarge the quantity of iron is too small to render it of any commercial value. There can be no doubt that the iron of this district has been derived from the decomposition of the basalt, and in this connection it is interesting to bear in mind the large percentage of iron that sometimes occurs in basaltic rocks, such as those of the Sandwich Islands.

The tertiary iron ore of Antrim extends along the coast from Cushendall to Carrickfergus, and for a distance inland, which varies from two to ten miles.

Important mines are situate at Glenarm, Carinlough, Cargan, Newton Crommellin, Glenariff, and Irish Hill near Ballyclare.[1]

European Iron Ores.

Spain.—The larger part of the foreign ores of iron imported into this country is derived from Spain. It is found in the Carboniferous limestone near Bilbao, ranging as far as 19 miles north-west of that town. The principal ore is brown hematite with some spathic iron. It is quarried at the surface, and is worked chiefly in the Somorrostro district. Other iron mines occur near Carthagena, Santander, Granada, and in Catalonia.

Portugal.—In Portugal lodes of magnetic oxide of iron or magnetite occur in the Serra dos Monges in Alentejo. Other ores occur at Moncorvo and at Quadmaril in Tras os Montes.

France.—The iron ores of France are chiefly contained in the lower secondary rocks. The most important deposit extends from Luxembourg through Lorraine to beyond Nancy. It occurs in the Upper Lias. Other beds of the same age are found near Privas and La Voulte in Ardêche.

[1] Iron Ores of Antrim, J. D. Kendall, Proc., "North of England Institute of Mining Engineers," vol. xxx., 1880.

Italy.—The spathous iron and limonite of Lombardy are well known from the Lakes Como and Iseo, and the Bergamask mountains, occurring in the former localities in gneiss, and at the latter in Trias. Elba is rich in red hematite and specular iron.

Greece.—Iron ores of Greece are chiefly obtained from the island of Seriphos. They are partly magnetic ore and partly brown hematite.

Norway.—The iron ore of Norway is chiefly magnetic. It occurs in mica schist and hornblende schist, extending along the coast in the neighbourhood of Arendal and Kragero.

Sweden.—The ores of Sweden are partly contained in gneiss. The most important are in the neighbourhood of Dannemora and Taberg, where the ore contains titanium and vanadium.

Iron ores are widely distributed over Western Russia, especially in Finland.

PALÆONTOLOGY.

CHAPTER XXIV.

ELEMENTARY IDEAS IN PALÆONTOLOGY.

PALÆONTOLOGY is the history of the succession of life on the earth. It begins with a remote past, when the great groups of organisms were already characterised, and many surviving genera were in existence. It passes over long ages of past time, distinguished by ordinal groups of animals long since extinct. It follows the steps of geological history, and demonstrates how faunas and floras have been preserved by becoming adapted to the circumstances which succeeding ages produced. And it teaches how the existing distribution of life has been evolved during the past history of the earth. We thus learn that species are mutable; that their distribution is limited in space and time; that they are thrown off from a genus, like leaves from a tree, and that the genus survives by developing characters which repeatedly obliterate its specific identity. The alterations which time elaborates frequently affect the more vital structures, so that the genera in the older rocks are replaced by allied genera which vary, partly by increased growth of some parts with decreased growth in others. Every type of life passes through a series of changes comparable to those in the life of an individual, and species, genera, families, and orders all grow old, lose their vitality, and disappear from the life that survives. Other species and groups under new circumstances put on an amazing vitality, and increase at the expense of surrounding life, and become dominant in regions of the earth and periods of time. These are the abundant *demoid* types which are termed characteristic fossils, for their abundance is such that strata are easily recognised by them. Every formation has its demoid types, which in the Primary rocks are generally brachiopods, in secondary clays are oysters, and in the limestones are frequently ammonites, or terebratulæ. The dwindling or *asthenoid* species, by failing with different successive periods of time, have a value of another kind in associating rocks together in groups. These two types of life are the most interesting

in every stratum, for they give a facies to the fauna though the species may be numerically few.

Origin of Species.—The philosophy of palæontology was long retarded by the views held concerning the nature of species, and although it was considered that any number of varieties might be thrown off, all the varieties were imagined to be infertile, or to revert in a state of nature to the original type; and it was not until the publication by Mr. Charles Darwin, in 1859, of his work on "The Origin of Species," that naturalists began to conceive of the possibility of species coming into existence under laws which were closely associated with their gradual extinction. The two great principles which Mr. Darwin recognised as aiding the development of life were "the struggle for existence," and "the survival of the fittest,"—meaning by the struggle for existence the obvious fact that more individuals of all races are produced than can survive; and that those selected by Nature to survive are the individuals or races which have physical or mental advantages over the others; and that, by continuous variation, a divergence might in this way be produced which would result in the elaboration of new species. The origin of species, however, is not a simple process, and the cause of the structural variation is here left unexplained, or is assumed to be a matter of accident. This logical defect in Mr. Darwin's original argument retarded for a time the acceptation of his views, and led to a belief that the causes of evolution might admit of some elaboration. We had arrived, in 1862,[1] at the conclusion that, however important an agent in change the struggle for existence may be, the fundamental active principle in evolution is physiological causation, partly dependent upon external influences which govern the conditions of food supply, but more dependent upon circumstances which govern digestion, nutrition, and elimination of waste products and unused structures; and we still believe that too much attention cannot be given to the physiological aspects of evolution.

Thus, where animals are fixed on the sea-bed, and derive their food supplies from currents, or where animals are dependent on the vibratile motions of ciliæ, it is difficult always to realise the conditions of a struggle for existence, or the nature of endowments which would characterise a favoured race. But from the physiological point of view the problem is simpler, for all variation is ultimately a matter of organic dialysis, in which the action of the dialysing membrane of a tissue or organ varies with its own nutrition and physical conditions, and hence elaborates or eliminates more or less of a tissue, or modifies the tissue so as to vary the sum of the animal structures under the conditions of geological change. The principle which would account for the origin of species must be equally applicable to all types of life; and because there is nothing in common between all types of life except the modes of nutrition of the tissues, the func-

[1] Camb. Phil. Soc., March 17, 1862, "Researches on the Homologies of the Bivalve Mollusca, and therein of the Law of the Variation of Forms and the Nature of Genera." This memoir was only printed in abstract in the *Cambridge Chronicle*.

tions of the several organs, their dependence on each other, and the functions of the sum of the organs, we are compelled to recognise variation in the work performed by the whole of the organs, as the originating cause for that structural variation by which species are distinguished from each other. As an organ ceases to perform work, owing to the work being no longer necessary, or performed by some other part of the body, so there comes to be not merely change in the organs concerned, but in all other organs which are related to them, and often in the characters and habits of the organism as a whole. Just as in the individual, a certain degree of growth takes place with increased work, and a corresponding atrophy follows diminished work, so in wild active races bones are found to develop strong ridges and crests, and muscles acquire long ligaments, which are unknown in domesticated tribes;[1] and therefore nothing is needed to produce an infinity of variation in a type but ever-progressing atrophy and hypertrophy of its constituent structures, consequent on changed nutrition of the structures, which has resulted from the work they have had to perform. Side by side with variation in internal vital organisation, variation of another kind has gone on simultaneously, which has been due to the manner in which the changing conditions of existence have modified the purely muscular and skeletal elements of an animal. The directions of simultaneous variation may thus be numerous. If the variation progresses too rapidly for the organism to become adapted to the change, the modification is designated disease; but such variation, though leading to extinction of races, probably has little to do directly with the origin of species. The direction of physiological variation is always towards increased complexity of structure, but the direction of variation under external influences is often towards increased simplicity of structure.[2]

Genus and Species.—Whatever other classification may be adopted, every fossil, like every living plant and animal, must be referred to its genus and species, and we need to have clear ideas of the nature of the facts indicated by these terms. A genus is an organic variation from a group of structures such as is comprised under the natural history term Ordinal group, and is thrown off with distinctive characters which perpetuate the Order, in a direction which its structure and the animal's habits determine to be the direction of chief variation. Thus, among the bivalve shells termed Lamellibranchiata, the key to many generic modifications is found in the mode in which the development and arrangement of the digestive organs govern the position of the adductor muscles. In those types with a single central muscle, like the oyster, scallop, lima, the digestive canal is comparatively short and simple in its folds, and the axis of growth of the shell is at right angles to the axis of the digestive canal. But as the canal becomes more complicated, its change of position results in changed position of the adductor, and the development of a second adductor muscle, when the digestive tube becomes forced

[1] Darwin: "Variation of Plants and Animals under Domestication."

[2] "Origin of the Vertebrate Skeleton," Annals and Mag. Nat. Hist., November 1866, and April and July 1872.

into an organ which is termed the foot. The shape of the shell follows that of the animal, and becomes circular, oval, and more and more elongated transversely as the foot and digestive and respiratory organs become more modified in form. We may perhaps illustrate the nature of these modifications by examples. The common scallop is referred to the genus Pecten. The characters which are common to all species of Pecten are the definition of the genus, which the palæontologist needs to remember; they are three. First, a straight hinge-line; secondly, two lateral processes of shell called ears, at the sides of the central ligament of the hinge; and third, the axis of greatest growth at right angles to the central line of the hinge. No matter what other characters the shell might have, if it had these it would be a Pecten. The other characters would serve to distinguish species. They would be first, the relative length and breadth of the shell; second, the degree of inflation of its valves; third, the form and development of the ears; fourth, size; fifth, the external condition of the surface of the shell, which might be smooth, marked with many kinds of radiating ornament, or concentric ornament, or cancellate ornament, &c.; so that it is scarcely conceivable that any external specific character should approximate a pecten towards another genus. Yet a modification of one of the generic characters would permit of that character being associated with the whole series of secondary modifications of growth which we agree to designate specific. Thus, if while the hinge-line remains straight, as in Pecten, it is shortened so that the ears become smaller, and the axis of growth is inclined anteriorly, so that the anterior margin of the shell is straight or nearly so, and the posterior margin convexly rounded, a generic type results, which is indicated by the name Lima. Similarly, if the hinge-line is elongated by extending the ears, and the axis of growth is inclined posteriorly, the genus Avicula is defined, and it too may undergo variation, which is practically infinite, by modification of ornament and form. From Avicula many other genera may be derived; thus, by still further elongation of the hinge-line and increased obliquity of the axis of growth of the shell, the ears become entirely obliterated, forming the genus Pinna. There are some shells which, instead of growing only at the occludent margin, also grow at the hinge margin; and if we conceive of a form of Avicula in which the ears are small, and in which the shell is marked by fine radiating ribbing which reproduces itself in the hinge, as may be seen in thin shells like some species of Modiola or Crenella, then the step may easily be conceived by which a transition is made from Avicula to the genus Arca, characterised by its straight denticulated hinge-line and transverse and inflated mode of growth. Arca, through some of its fossil representatives, like Macrodon of the Great Oolite, reproduces the hinge-teeth of the genus Avicula, and Arca, by losing its ear-

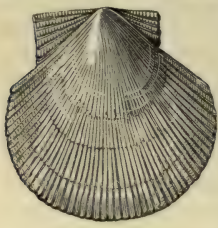


Fig. 80.—Pecten.

Fig. 81.—Avicula.

like appendages, acquires a circular outline and a crescent-shaped denticulate hinge-line, and becomes the genus Pectunculus. Isoarca is another modification in which the shell grows most rapidly at the anterior margin, so that the beaks recede from each other and become spiral, and the shell is globular. Pecten, by thickening the lower valve at the hinge, gives rise to the genus Spondylus ; and Spondylus, by losing the thickening and the ear-like appendages of the hinge, but retaining the interlocking denticles of the hinge, becomes the genus Plicatula. We might in this way show how all the genera of shells are related to each other, and may well have been derived from a few recognisable types by growth in some directions and atrophy in others. But our object is rather to exhibit the nature of generic characters, so that the eye of the student may be educated to discern the characters which follow a plan, and thus discriminate genera,[1] recognise their affinities, and identify species.

Fresh-water Deposits.—The great divisions of strata into fresh-water and marine deposits are recognised by fossils. Some fresh-water strata certainly were deposited during the Primary period, especially among the Coal-Measures ; but with the exception of Anodonta Jukesii, found in the Upper Old Red Sandstone of Kiltorkan, in Kilkenny, they yield no fresh-water fossil referable to an existing genus. But in the Secondary and Tertiary periods, not only are all the fossils which occur in British fresh-water beds species of existing genera, but the genera are all of the same types as still live in fresh waters in the British area. Among GASTEROPODA the characteristic genera are—

Fig. 82.—Planorbis.

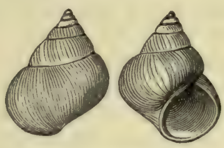


Fig. 83.—Paludina.

Limnæa. *Planorbis.* *Paludina.*
Physa. *Valvata.* *Neritina.* *Ancylus.*

The characteristic LAMELLIBRANCHIATA are—

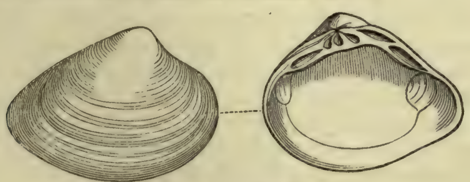


Fig. 84.—Cyrena.

Unio. *Anodonta.* *Cyrena.*[2]
Cyclas.

[1] "Identification of Fossil Bivalve Shells," Geologist, Feb. 1864.

[2] Several marine types have fresh-water representatives. Thus the marine *Mytilus* is represented by *Dreissena*, the marine *Arca* by fresh-water species in the Ganges and South-east Asia.

These genera are found in the Secondary Rocks in the Purbeck and Wealden Beds; and in the Lower Tertiary lacustrine beds of the Isle of Wight, known as Headon and Bembridge Beds; and in the valley gravels.

Fresh-water deposits often contain pulmonate land gasteropoda, such as *Helix*, *Bulimus*, *Pupa*, *Clausilia*, *Cyclostoma;* together with land mammals, birds, reptiles, and land plants.

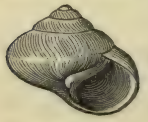


Fig. 85.—Helix.

The absence of fossil species of the following groups is to be expected in fresh-water strata:—Foraminifera, Sponges, Corals, Echinoderms, Cephalopod Mollusca, Brachiopoda, and Bryozoa. All these groups are typically marine; though foraminifera live in the Thames at Gravesend, and Spongilla is characteristic of fresh-water ponds.

Estuarine and Brackish-water Deposits.—There are some genera which are typical of the mouths of rivers, and such forms may be termed estuarine; but whether they have always existed under such conditions, may well be doubted. Among the more remarkable of such genera may be mentioned *Potamides*, *Cerithium*, *Melania*, *Melanopsis*, *Auricula*, *Nerita*, *Mya*, *Scrobicularia*, *Cyrena;* and a predominance of such types in a stratum would justify us in affirming its estuarine origin. Examples of strata showing such conditions may be seen in the Woolwich and Reading beds between Upnor and Dulwich, and certain beds of the fresh-water tertiary series of the Isle of Wight. But towards the mouths of rivers the marine shells become modified in form and regularity of growth and ornament, by the influence of fresh water, so that varieties are developed which, in their divergence, at first suggest to the collector a multitude of species. Such variation is well known in the Caspian, and Sea of Aral, and Black Sea, at the mouths of rivers, especially among species of Cardium. It is strikingly shown in the estuarine part of the Red Crag, known as the Norwich Crag, in which the *Fusus antiquus* and *Purpura lapillis* are singularly variable.

Fig 86.—Melania.

Shallow-water Deposits.—The geologist will always judge from physical evidence of the conditions of deposition of a stratum. Conglomerates and grits must be shallow-water deposits. Sandstones are likely to be accumulated in shallow water, and no evidence can override the presence in them of false bedding and ripple-mark. But mineral character alone is not always proof of nearness to shore of a stratum, for that may change with the nature of the coast wasted. At the present day no one would hesitate to affirm low-water conditions for a collection of living British shells which included—

Purpura.	*Nassa.*	*Trochus.*	*Littorina.*
Patella.	*Haliotis.*	*Pecten.*	*Mytilus.*
Cardium.	*Tapes.*	*Solen.*	*Pholas.*

We might enlarge the list by taking from other waters species of—

Conus.	*Planaxis.*	*Emarginula.*	*Modiola.*
Pleurotoma.	*Columbella.*	*Chiton.*	*Arca.*
Mitra.	*Pisania.*	*Bulla.*	*Chama.*
Cypræa.	*Murex.*	*Pinna.*	*Mactra*, &c.

which indicate in most cases low-water conditions. If, then, these genera occur in association in an ancient deposit, we are required to believe, if we affirm shallow-water conditions for the stratum, that the changes in level of the ancient sea-bed went on so slowly that the life gradually accommodated itself to change, finding the conditions of existence easier by following the coast-line than by remaining fixed on the sea-bed. This migration of life is implied in the recognition of an ancient sea margin or shallow ocean by characteristic fossils.

Marine Deposits of the Open Ocean.—The deep waters of the ocean, formerly thought to be barren, were proved by the researches of Dr. Carpenter, Dr. Gwyn Jeffreys, Sir Wyville Thompson,[1] and Professor Sars, to be rich in life, though Dr. Wallich, in his account of the voyage of the *Bulldog*, was the first to make known the occurrence of deep-water foraminifera, shells, and echinoderms in the northern seas. Dr. Carpenter observes that the abundance and variety of animal life on a bottom on which the temperature is at least 2° F. below the freezing point of fresh water, is a fact which has all the interest of surprise ; and it is scarcely less remarkable that the forms of molluscs, echinoderms, and sponges, which seem to be characteristic inhabitants of this cold area, should attain a very considerable size. The deep-sea exploration has yielded many genera previously supposed to be extinct, and many types allied to extinct genera of the secondary strata. Thus a crinoid from a depth of 2435 fathoms belongs to the extinct apiocrinite type, and is associated with an urchin allied to the flexible Echinothuria of the chalk. The vitreous sponges, like Holtenia, recall fossil sponges of the Upper Greensand and Chalk ; while the foraminifera and polycystinæ present a similar interest. Of the foraminifera, Globigerina and Orbulina live on the surface of the ocean, and like the pteropods only reach the deeper waters after death, when they are mixed with heavier-shelled forms which live on the ocean floor.

Extinction of Species.—Species are most easily exterminated by the struggle for existence. They drop away one by one, first by diminution in numbers, then by limitation of the inhabited area, till they cease to be met with in geological time. This process is similar to that which has been recorded in human history, by which so many birds have disappeared from the earth. Not to mention the moas, still found with the feathers attached and with moa eggs buried in Maori graves, there are the well-authenticated instances of the dodo of Mauritius, and the solitaire of Réunion ; and Professor Alfred Newton[2] records, among other extinct Mascarene birds, in addition

[1] "Depths of the Sea ;" and "Voyage of the Challenger in the Atlantic."
[2] Encyc. Brit., article "Birds."

to the crested parrot, two other parrots, a dove, a large coot, an abnormal starling, a ralline bird incapable of flight, and many others. The Antilles have in the same way lost in the last century many macaws and other species; while the garefowl, Alca impinnis, has disappeared along with the Labrador duck and the Philip Island parrot, Nestor productus. Evidence of the process of extinction may be traced in our own country, in the changed and more limited distribution of the crane, spoonbill, capercailzie, bustard, &c. And if we go back to the remains preserved in beds of peat, we add to our British fauna the pelican, wolf, brown bear, roebuck, Bos primigenius, Bos frontosus, the Irish elk, and beaver, which were certainly contemporary with man. Species have a life like individuals; some insects which live but a single season have been kept alive for many years by preventing them from experiencing the change of temperature under which reproduction and death occur. And so species by existing under similar conditions may undergo little or no change, and survive through long periods of geological time; but as a rule, a species, however dominant it may become for a time, by immunity from enemies, or organisms causing disease which have not become accustomed to their new companion, sooner or later fails in physiological vitality if it is exposed to the ordinary variable conditions of climate; and then disease attacks the species with fatal energy. Many instances might be recorded of the wholesale death of mammals from drought, and of fishes from poisoned water, which would parallel anything met with among the strata.

Sudden Destruction of Marine Animals.—The extraordinary abundance of fossils in some deposits, and the evidences of the sudden death of others, do not imply any wholesale extinction of life, but rather such destruction as occurs from time to time by natural agencies. Professor Rupert Jones, F.R.S., records several such phenomena. Thus lobsters have been killed in the boxes in which they are kept at the bottom of the sea at Stornoway by a heavy fall of rain in the night. The octopus has been similarly cast on shore in immense numbers after the passage to the sea of floods of snow water. The great rains of the south-west monsoon kill thousands of fishes and other sea animals on the coast of India. Star-fishes and other marine animals have been found killed on the south of Tobago by the fresh waters of the Orinoco. Even the Yenisei in flood kills the deep-sea fish of the Arctic Ocean. The fishes of the Jordan are similarly killed when carried into the Dead Sea. The heat from volcanic eruptions has killed fishes in all parts of the globe. A bank of crabs three feet high was thrown up after an earthquake-shock in the Bay of Payta in Peru. Storms sometimes kill millions of oysters, and storms are probably the most destructive agents affecting fishes. Occasionally the sea-bed is seen covered for acres with the dead sand-lance and other fishes. Sometimes an epidemic affects fishes, and salmon die in great numbers, and may even die under the influence of unusual heat. By drying up the coast in estuaries, eels have been killed in hot seasons on the coast of France in sufficient numbers to

produce fever. A ferruginous spring entering a river may kill the fish for miles.[1] Such and such-like conditions may account for the appearances of sudden mortality which are familiar to the geologist, but the extinction of species even locally is a phenomenon of another order, and is in most cases to be attributed to the upheaval and depression of land.

Palæontological Laws.—Pictet summarised palæontological belief in the following laws:—1. All species have had a limited geological duration. 2. The contemporary species of a geological fauna in any one locality in most cases appeared simultaneously, and disappeared in the same manner. 3. The differences between living and extinct faunas are in proportion to the geological antiquity of the extinct fauna. 4. The diversity of animal organisation has increased with the duration of geological time. 5. The highest types of life have a comparatively recent origin. 6. The order of appearance on the earth of the different types of life often recalls the phases of embryological development. 7. The existence of a type upon the earth is uninterrupted from its first appearance to its extinction. 8. The ancient distribution of life shows that the distribution of temperature has changed. 9. The geographical distribution of species found in the strata was more extended than the range of species of existing faunas. 10. Fossil animals were constructed on the same plan as existing animals, and their lives manifested the same physiological functions.[2]

Succession of Life in Time.—Just as the earth's surface at the present day is inhabited by groups of animals and plants, as distinct from each other as are the faunas of past ages of geological time, so every era, the earth being divided up into masses of land and water, must always have had its life characterised by differences in the generic groups of species in different regions, which amounted to provinces, comparable to those which have been established upon the distribution of living animals and plants. Hence the fauna or flora of a geological formation is nothing but a natural history life province, which has become preserved in sediments, which enclosed organic remains in the positions in which they once lived, and are now found. And every life province, whether on land or in the sea, is only a geological fauna or flora which is now becoming fossilised. Formerly there was a belief that the physical conditions which caused the deposition of a new mineral sediment affected the whole surface of the earth, or were of the nature of "catastrophes," and that many successive creations replaced the life which was supposed to have been periodically exterminated. Such ideas of catastrophe and creation find no support in the observations which geologists have accumulated. On the other hand, Lyell and Darwin, and the uniformitarian school, by supposing that life, when it was once placed upon the earth, had become gradually and successively modified from age to age, appealed to "breaks in time" and the "*imperfection of the geological record*," as means of accounting for differences which were

[1] Geol. Mag., vol. ix. p. 533.
[2] "Traité de Palæontologie," tome i. 1853.

found in the faunas of successive rocks. A slight difference in the life in an overlying deposit was thought to imply a moderate denudation, or a short interval in deposition. Great changes were held to imply great denudation, and vast gaps utterly unrepresented by strata. We escape from both of these hypotheses in better geographical knowledge of the distribution of life. For, although we must appeal on the one hand to great upheavals and depressions of land, which are essentially catastrophes in their effects, and have no choice but accept the evidences of evolution concerning the variability of organic types, and must allow that many of these are lost to us through denudation of strata during the elevation and depression of ancient lands, yet nothing but the succession of life provinces, superimposed vertically upon each other, can account for the succession of life which the fossiliferous strata disclose.[1]

Migration of Life Provinces.—When life is traced back in time in any part of the earth, the geographical distribution of species is found to differ from the existing distribution. Thus, in the peat of the fen district of the eastern counties, several mammals occur fossilised, such as the Bos primigenius, the Bos frontosus, and the Cervus megaceros, which are now extinct, and these are associated with the brown bear, wolf, beaver, roebuck, and other species which have long since become extinct in these islands, or more limited in range. Similarly we may compare the mammals of the peat with those found in the valley gravels, with the result that some species of the peat, like the Bos primigenius and the Cervus megaceros, are still met with, associated with hippopotamus, lion, rhinoceros, elephants, and other types which present a remarkable correspondence to the mammal life of Northern Africa. We can only explain this succession of life in the same district on the hypothesis of migration from some neighbouring district, and must seek back for the origin of the fauna of the gravel in the Newer Tertiary strata. We may not be justified in inferring that the gravel fauna reached North Africa by migration from Europe, though it is highly probable that the upheaval of Northern Europe which produced the glacial period necessitated a migration of the crag fauna southward, and that the mammalia returned again to the north as the land resumed its ordinary vegetation on being again depressed. Another instance which might be adduced as tending to show how the limits of mammalian provinces of life have varied in past geological time may be found in the types by which the Crag deposits of the eastern counties show connections with the Oriental region. Not to mention the mastodons, elephants, rhinoceroses, which have Eastern affinities, there is a tapir in the Crag comparable to the Malayan tapir, and the Hyænarctos, which closely resembles the same genus in the Siwalik rocks of Northern India. This migration of mammal life is in harmony with the migration of plant life.

At the present day Japan belongs to a different natural history

[1] "Laws which have determined the Distribution of Life and of Rocks," Annals and Mag. Nat. Hist., December 1867.

province from India, but it was not always so; for the Stegodon clifti, Stegodon insignis, Elephas namadicus, and Elephas primigenius, which are fossils found in the Siwalik and Narbadda deposits, also occur in Japan, presumably of the same age.[1]

The Siwalik fossils comprise far more African types than are found living in India, and they also include many genera which are met with in the older Tertiary rocks of Europe. And just as we are entitled to infer that such genera as Hyopotamus and Anthracotherium and Acerotherium, which occur in the Miocene of Europe, migrated eastward to from part of the Siwalik fauna, so we may conclude that the giraffe and ostrich, which were Siwalik types of life in the Pliocene period, migrated from India to Africa, and therefore we must look to this ancient geological connection for an explanation of the partial community of life between the existing Ethiopian and Oriental regions. There is no element in a fauna, so far as we are aware, in any period of geological time which does not prove this migration to have been always in progress.

Origin of Faunas.—Suppose, by way of hypothesis, that we have to deal with a world in which the surface may be divided into natural history provinces, defined like the spaces on a chess-board, where the value of the moves of the several pieces is different, and that after the life has accumulated on a given area, R, upheaval affects the sea-bed of an adjacent region along a line A, B. The result of this upheaval is to displace the life from the region S, which adjoined the line A, B, and cause it to migrate to the region R; it thus becomes mixed with the life in R. But since the sea-bed at R has itself undergone change, some of its life has migrated away, some species have been exterminated by the altered circumstances, and similarly the immigrating group loses some of the forms which were characteristic of it when occupying the region S. These losses may be designated X. Hence a new fauna is compounded out of pre-existing groups, and does not correspond with that which would be obtained by simply mixing them. And just as some species of plants and animals taken to new regions increase to an unheard-of extent, as the Anacharis increased in our own country, the thistle in New Zealand, the rabbit in South Australia, so in the history of life every province becomes enriched by species which were previously unknown, unimportant, or rare, that under their new geographical conditions come to be dominant in number of individuals, and often in variation. This gain to the province may be termed Y. Similarly, if a change in the amount of elevation of the axis A, B, at one end of the axis towards A, comes to lay bare the sea-bed in the region T, and causes the life of this region to be superimposed upon the spot where the life R was fossilised, and where the life $R + S - X + Y$ was superimposed upon it, then a third fauna will succeed, which may differ from the second as much as the second differs from the first, which must have been compounded out of older groups, and must itself undergo the loss indicated by X, and acquire the facies indicated by Y. In this

[1] R. Lydekker: "Palæontologia Indica."

hypothesis we have supposed the conditions of the sea-bed to remain essentially the same in the locality R; but it is obvious that depression might produce in that region deep-sea conditions, and cause the influx of a deep-sea fauna, or that elevation might develop laminarian or littoral conditions, so that the variations of the fauna which are possible, without seriously affecting the distribution of land and water on the earth's surface, are more numerous than might at first sight appear. Similarly, when a land emerges from the sea, the life which covered that area is displaced, and the rising land divides the marine fauna, so as to cause the group to be pushed apart as the island enlarges into a continent, until by following the littoral or laminarian zones which offered the conditions of least resistance to their movement, it has happened that the fauna, which was originally temperate, has in part become arctic; in another part has become tropical; while temperate provinces are found in temperate latitudes. If a land surface becomes enlarged, the life diffuses itself, so that the species are few relatively to the area; but if the land is undergoing depression, then the fauna and flora become rich, because the area of land decreases without any corresponding decrease in the variety of life. The whole doctrine of the identification of strata by means of organic remains, rests upon the assumption that the strata identified were deposited in the same natural history province. If strata are defined to be of the same age from their fossils, it can only be because the old life province can be traced continuously from one point to the other. But great practical difficulties result from the imperfection of our knowledge of the past distribution of life; for though 95 per cent. of the shells of the Red Crag are still living, a much smaller percentage of British shells will be found in the fauna of Portugal; so that contemporary faunas, even when separated by moderate distances, may have less in common than faunas of different geological ages which are superimposed on each other.

Identification of Strata by Fossils.—As taught by William Smith, the identification of strata by fossils was a matter of observation. He used fossils as an aid in tracing the strata through England. The results, as displayed in his books and maps, were so remarkable, that the principle, which in his hands was sound, came to be regarded as a universal law, though no conditions were imposed on its application. The British strata were taken as types, and British fossils found in distant places spread William Smith's names for the beds over Europe. And before long the great divisions of geological time, thus marked out conveniently, came to be recognised over distant parts of the globe, and their ages were determined by their fossils. This was not a scientific use of fossils, for it ignored the origin and distribution of species. It led to the theo-geological conception of successive creations and extinctions of life on the earth, which marked off the range of species exactly. But when it came to be seen, by detailed examination of strata, that there was no such homogeneous group of life in a period of time, but that the life changed all through a formation, approximating to the older life in the bottom beds, and to newer life in the top beds, we

reached the conception of a continuous succession of life on the earth, modified in successive periods through all past time. Still this did not invalidate the doctrine of the identification of strata by fossils, though geologists began to find from experience, and taught that some species lost their identity more rapidly than others, and that species have different values in identifying strata. After Edward Forbes had marked out the limits of life in zones of depth, and in his "Natural History of the European Sea" had traced the limits and life of existing natural history provinces, and in his discussion of the geological relations of the British fauna and flora, had traced the geographical and geological antecedents of existing life,[1] only an effort of the imagination was needed to set the existing life provinces in motion with the upheaval and depression of land, and see that the succession of life in time implied migration, and therefore that no flora or fauna was ever universal.[2] This discovery limited the idea of identification of strata by fossils; for it implied that similar fossils could only prove the continuity of a stratum when the deposit took place in the same zoological province. The moment we travel beyond that central part of the province where its typical species and genera abound, so soon do we find a greater change in life than the geologist would expect in a stratum. It is impossible to run a line along the sea-bed from Britain north to Spitzbergen, or south to the Azores, south-west to the West Indies, or west to Labrador, without passing over groups of organisms which if fossilised would *not* tend to establish contemporaneous deposition by community of life. Among many groups of animals there are species which are world-wide; but the wider the range in space the longer is the duration in time, and therefore the less the value in identifying a stratum; and in existing seas a geographical interval means a change in fauna. So must it have been in all past time; otherwise there could have been no succession of life in time. It may have been that life provinces in the sea were as numerous in primary or secondary ages as they are now; in any case we must appeal to them in explanation of the successive changes of life in the geological formations of any one district; and we cannot imagine such geographical changes as would produce succession of strata, without the elaboration of life provinces at the same time. If we recognise this ancient arrangement of life, then it follows that the life of several geological formations existed simultaneously in the same sea, otherwise they could not have been superimposed. That is to say, the life which we term Silurian, Devonian, Carboniferous, must in its main elements have been contemporaneous in horizontal succession in the oceans of the ancient world, otherwise it could not have been accumulated in vertical succession in the strata. But if these faunas were contemporaneous, the fossils cannot identify different limited periods of time in widely separated localities.

Homotaxis.—De la Beche[3] was the first to recognise the difficulties

[1] Mem. Geol. Survey, vol. i. 1846.
[2] Annal. and Mag. Nat. Hist. Dec. 1867.
[3] "Researches in Theoretical Geology," p. 261. 1834.

in the way of identifying strata by fossils, for he observes that if the coasts on two sides of a sea are so situate that the one is subject to oscillations, rising above or falling beneath the general ocean level, while the other remained firm, we should obtain different results. In the one case there would be the exuviæ characteristic of a marine deposit with unchanged mineralogical structure, while, in the other, there might be great variety in the life, or a destruction of species which continued to exist unchanged in the other situation, so that there would be little or no resemblance in the organic contents of contemporaneous rocks. Similar views were long afterwards restated by Mr. Herbert Spencer in an anonymous article entitled "Illogical Geology," since reprinted.[1]

Subsequently, in 1862, Professor Huxley[2] discussed the question in an address to the Geological Society, and after demonstrating that geology can only prove a local order of succession, goes on to state that for areas of moderate extent no practical inconvenience is likely to result from assuming the corresponding strata to be synchronous. But the moment the geologist has to deal with the large areas or completely separated deposits, then the mischief of confounding that homotaxis, or "similarity of arrangement," which can be demonstrated, with synchrony or identity of date, for which there is not a shadow of proof, under the one common term of contemporaneity, becomes incalculable, and proves the constant source of gratuitous speculations. Hence[3] it is possible that similar or even identical faunas and floras, in two different localities, may be of extremely different ages, if the term age is used in its proper chronological sense.

Barrande's Colonies.—Edward Forbes enunciated the doctrine that when a species is once extinct it never reappears. But the disappearance of a species from a stratum succeeding that in which it is found, does not, however, imply extinction. Barrande conceived of the idea that assemblages of species, forming the fauna of a sea-bed, might migrate away in one age, and return again to the same district in a later period of time. This first appearance of the same fauna he terms a colony. The Cambrian rocks of Bohemia exhibit many examples of such colonies. The reality of these colonies has been attacked and defended. The great difficulty in accepting them is not so much the inherent improbability of the repetition of the same life group in the same district, as the universal absence of such a phenomenon in the newer strata. This assumed repetition reminds us of the old assertion on which the name Lower Silurian was first instituted, that the fossils found in the Upper Silurian also characterised the Lower Silurian. This repetition existed, and is now well known to have been due to inversion of the strata, so that the Lower Silurian were the Upper Silurian. Mr. J. E. Marr has similarly suggested that the colonies of Barrande are due to the same strata being repeated by inversion and contortion.

Persistent Types of Life.—In the succession of life exhibited

[1] Essays. [2] Huxley Address, Geol. Soc. 1862.
[3] Huxley Address, Geol. Soc. 1870.

by the strata, nothing probably is more astonishing than the evidence afforded of the way in which the principal types of life have persisted on the earth. This correspondence between the ancient life and the existing life was first enunciated in recent times by Professor Huxley.[1] It has been shown that the *Lepidodendron* of the coal-measures in all essential details of structure is closely allied to the living *Lycopodium*.[2] Species of *Araucaria* are known from the oolites which also contain species of *Pinites*, while the cretaceous rocks yield species of *Cedrus*, pandanaceous fruits, *Juglans* (walnut), and a multitude of other genera which still exist, and are met with throughout the Tertiary period. This history is repeated by almost every group of animals. The foraminifera of the Carboniferous period, together with many extinct types, include existing genera (see p. 479). Among the alcyonarians, the fossil *Heliolites* makes a remarkable approximation to the surviving *Heliopora*. The great existing divisions of sponges date back in time to the oldest rocks; while the Mollusca are for the most part represented at the present day by genera in which the generic characters have remained unchanged through all geological time. The *Nautilus* ranges through all strata. The *Loligo* commenced with the Lias and lives on to the present day. Among gasteropods, *Patella*, *Dentalium*, *Trochus*, *Natica*, *Chemnitzia*, are common genera which all date back at least as far as the middle of the Primary period. The bivalve shells tell the same story, *Arca*, *Avicula*, *Lucina*, *Cardium*, *Pinna*, *Pecten*, are all types which date from the Primary epoch. Among brachiopods, *Crania*, *Discina*, *Lingula*, *Rhynchonella*, and *Terebratula* are genera met with plentifully in early Primary rocks. Among Annulose animals the Carboniferous rocks have yielded scorpions, spiders, centipedes, and representatives of the chief groups of insects and crustacea. Nor are the vertebrata an exception to this general law of the antiquity of life, for the oldest fishes belonged to living groups, and the Elasmobranch and Ganoid groups of the Palæichthyes date from before the middle of the Palæozoic period. The Amphibia at their first appearance present a higher type in some respects than any which now survive. The Crocodilia, Chelonia, and Lacertilia, date from the secondary epoch; and in the older Tertiary rocks serpents are found, differentiated as in existing groups. The few slight indications of birds found in the Cambridge Greensand, combine in one type characters of divers, grebes, and penguins; while even the Mammalia in their oldest forms show, as far as can be judged from a few bones in the lower oolites, and a few teeth from the Trias, the essential organisation of existing marsupials. We therefore discover that on the hypothesis of evolution, geological history does not carry us back appreciably towards the origin of the great divisions of organic nature; or even towards the origin of the chief generic groups. Hence it becomes rather a matter for wonder that the changes in life should have been so slight with the successive physical circumstances which have changed the distribution of land

[1] Royal Institution: Friday, June 3, 1859.
[2] Carruthers, Royal Institution, April 16, 1869.

and water, and brought new lands into existence in geological time. For they have so changed the distribution of life on the earth as to entomb and fossilise successively thirty or more distinct faunas in the sediments laid down upon the same area of sea-bed. Professor Huxley at first, perhaps, showed excessive caution in the statement—"There may, or there may not, have been a progressive development of animal and vegetable life; but the palæontological evidence before us does not justify the assertion that any proof of such progressive change, if it ever occurred, exists;"[1] but subsequently, in elucidating the evolution of the horse[2] and other animals, demonstrated that the discoveries of palæontologists have justified an abandonment of this negative attitude.

Ancient Types of Echinoderms now Living.—*Cidaris* is the oldest living genus reaching back to the Trias. At the present day its habitat is littoral. Among genera which survive from the Jurassic rocks are *Echinobrissus*, which is littoral, and *Hemipedina* and *Pygaster*, which are found in deeper water. The genera which live on from the chalk number 13. Of these 8 are now found in the littoral zone including *Leiocidaris*, *Echinus*, *Echinocyamus*, *Fibularia*, *Rhynchopygus*, *Nucleolites*, *Hemiaster*. The range of some of these genera in depth is less restricted. Thus the laminarian zone includes *Salenia*, *Cottaldia*, *Echinus*, *Echinocyamus*, *Fibularia*, *Conoclypeus*, *Catopygus*, *Hemiaster*, and *Periaster;* while the deep sea yields *Salenia*, *Echinus*, *Echinocyamus*, *Fibularia*, and *Hemiaster*, which are all Cretaceous genera. It is highly probable that the conditions of depth in which Echinoderms live have changed with geological time, for at the present day we might quote as representatives of littoral conditions most of the Cidaridæ, Diademadæ, Triplechinidæ, Temnopleuridæ, Nucleolitidæ, Echinonæ, and Palæostominæ. Laminarian conditions are represented by the Salenidæ, Galeritidæ, and many of the Fibularina and Nucleolitidæ.[3] The families of the Abyssal Ocean are the Ananchytidæ and Echinothuridæ. Therefore, inferences as to the conditions of life of an Echinoderm fauna, like that of the Upper Chalk, need to be very diffident.

Local Persistence of Types.—One of the most interesting problems, and at the same time one of the most difficult of explanation, is the persistence in the same locality of types which have undergone remarkable change; for it seems to be associated with absence of competition from more highly organised races. This succession is most striking among the mammalia of the more recent deposits as compared with living groups. Thus in South America the *Edentates* reach their maximum development, and it is among the muds of the pampas that we find the gigantic *Megatherium* and *Mylodon*, *Megalonyx* and *Scelidotherium*, representing the living sloths. In the same way the living

[1] Catalogue of a collection of fossils in the Museum of Practical Geology, with an explanatory introduction by Thomas H. Huxley and Robert Etheridge, 1865.

[2] Address Geol. Soc. 1870.

[3] Neumayr: "Neuen Jahrbuch für Min." 1882.

armadillos are represented by extinct gigantic *Glyptodons*, in which the armour is free from joints, and the living *Auchenia* is represented by the larger *Macrauchenia*. The monkey, *Protopithecus*, which occurs with them, is of the American platyrhine group.[1]

Similarly, in Australia the *Marsupials* reach their maximum; and here also gigantic forms occur fossil, and represent most of the groups. *Thylacoleo* is considered to represent a marsupial carnivore; *Diprotodon* is termed a marsupial pachyderm. Wombats occur as large as tapirs, and there were gigantic kangaroos and large phalangers. It is remarkable that the living Australian lizard Moloch appears to be represented in a fossil state by a gigantic prototype, *Megalania*. In New Zealand there are found in a barely fossil condition the remains of multitudinous gigantic birds, the most familiar of which is the *Dinornis*, and these may be regarded as represented at the present day by the surviving ratitæ of the Australian province. All giant types appear to have had a short duration in time.

Climatal Conditions of Ancient Seas.—Any attempt to estimate climatal conditions in past ages of the earth's history must rest upon physical evidence. Ice-scratched stones, glaciated rocks, and boulder clay may prove conditions of great cold, but we are acquainted with no physical evidence that would demonstrate heat as a climatic condition of the earth. There is nothing in the condition of the skeleton of the musk ox that would indicate the conditions of extreme cold under which the species lives, and no one examining the arctic seals in a fossil state could affirm that they had not lived in tropical waters. It is equally impossible to recognise climatic conditions from structure, collocation of species, or other evidence, for the abundant tertiary flora of Greenland, with its many sub-tropical types, has shown that the distribution of land and water may enable plants as well as animals to flourish in latitudes where their existence would not be suspected from the present distribution of life. Edward Forbes laid down the great doctrine that "every species is controlled by its own peculiar laws, and no acquaintance with one species of a genus, however extensive and accurate, warrants us in predicting concerning any other species, even though very striking resemblances may prevail; for the truths of zoology forbid us to reason concerning the species of a genus in the same manner as we do with the individuals of a species." Many genera are world-wide in distribution, and the habits, food, and climate of one species are quite dissimilar from those of other species. If, then, one recent species cannot indicate the climate under which another species lived, least of all can rare and surviving recent species tell anything of the climatic adaptability of extinct fossil forms. We need scarcely recall attention to the inferences which were drawn when the valley gravels of England first yielded the remains of elephant, rhinoceros, hippopotamus, lion, and associated species, in days before the glacial period was recognised. Such species were almost everywhere affirmed to indicate for Britain a warmer climate in the time when the fossils lived. Subsequently, when the same

[1] Owen's "Palæontology," 1862.

mammoth was found frozen in Arctic ice, the conclusion veered round; so that the animals, previously supposed to be sub-tropical, were believed to have lived under colder conditions than the present British climate. Such an example may warn us that, although the Nipa fruit of the London clay of Sheppey is of the same genus as the Nipa of the Ganges and Irrawaddy, and although associated in both cases with crocodiles and fresh-water turtles, in a sediment which includes many genera of shells found in eastern seas, we can no more infer a sub-tropical climate for the plant life or reptiles or shells of the London clay, than we can for the mammals of the gravel, which are often inseparable as species, from the similar assemblage of mammals now inhabiting the North of Africa. There has been a tendency to hasty generalisation in the matter of climate, as inferred from palæontological evidence.

It has often been pointed out that there is a correspondence between the marsupial mammals of the Stonesfield slate and associated cestraciont fishes, plants, and shells like Trigonia, with similar forms now living in the Australian region; and the conclusion has been drawn that the British fossil fauna and flora of Stonesfield lived under like conditions of climate. For such a view to be sustained, it must be held, either that the Australian life is a survival of a creation which was once universal, and of which a part was fossilised at Stonesfield, or else that the life from Stonesfield migrated through the equatorial region to the antipodes. Both views are equally untenable; the former being disposed of by the occurrence of Cretaceous and Tertiary strata in Australia, and the latter by the fact that, though it is just possible that elevation of land might preserve equable conditions between Britain and the antipodes, so that the equator should be passed without the experience of an equatorial climate, yet this hypothesis would require that the marine life should similarly and simultaneously migrate along a sea-bed, depressed so deep in the equatorial region that the climate was still temperate.

It is difficult, when dealing with living species in the newer geological formations, to be sure that we do not attach too much importance to the facies of the faunas of the Coralline Crag and the Middle Glacial sands, as indicative of climate. For although the *Pyrula*, *Cassidaria*, *Voluta*, *Lingula*, &c., of the Crag, suggest southern seas, and though the same area came to be occupied subsequently by an assemblage of shells which is now arctic, it is quite possible that climate may have had nothing to do with the succession, but that it may have been a continuous though slow migration of life southward, consequent upon continued elevation of land to the north.[1]

Existing Distribution of Life.—Since existing plants and animals are the surviving descendants of fossilised forms which in bygone time were distributed to different regions of the world from those which their descendants occupy, it is only natural to find that the great geographical groups of life on land do not coincide with present arrangements of land and water. In fact, the present distribution

[1] Cambridge Phil. Soc., March 3, 1862.

depends, first, upon the distribution in past time; and, secondly, upon the great physical changes which brought the known masses of land into existence. Edward Forbes long since recognised the law that life diffuses itself in the main under climatic conditions.[1] We may say that life diffuses itself in the direction of least resistance, which term may conveniently indicate comparatively uniform conditions of life. The influence of climate is obvious, because it implies similar physiological action for the parts of an organism and similar conditions of nutrition, as well as similar food. And the low forms of life may find similar climatic conditions in the deep waters of the tropics, to those which are presented by the shallow waters of the arctic seas; so that all over the world the life of the deep ocean forms as Sir Wyville Thomson observed, one natural history province so far as its lower organisms are concerned. How far this uniformity may be the consequence of the existence of deep-sea currents, diffusing the cold water and the germs of life within it, may perhaps be worth consideration. In like manner, above the surface of the earth there is a zone of comparatively uniform climatic conditions, which ascends from the poles higher and higher above the sea, following the snow-line, until, at about 16,000 feet of elevation in the tropics, the life is in the main the same in kind as that within the arctic circle. These aspects of climate are complicated, however, by variations in pressure of air and water, and this difference of pressure has a value in elaborating structures by inducing modified functions; so that the term alpine is not always synonymous with arctic, just as the deep ocean has yielded many forms of life which are unknown in the polar waters. The ordinary conception of climate, however, as indicated by limits of latitude, is exhibited in the distribution of many groups of organisms like reef-building corals. There are probably no conditions of climate to which life may not adapt itself, or be compelled to adapt itself, by physical circumstances. Perhaps the influence of coast-lines is one of the most important influences tending to modify the distribution of marine life in directions which are different, because not only is the water aerated by tidal action near to shore, but the conditions of existence are similar at similar depths. Edward Forbes observed the superposition of distinct faunas on the same shore. He defined by the term littoral all such animals as lived between tide-marks; laminarian zone was the home of the laminaria and similar sea-weeds, in water reaching from low tide to fifteen fathoms, where in our own seas the larger number of vegetable-feeding mollusca, as well as the carnivorous mollusca like buccinum, nassa, and natica, abound. Below this is the coralline zone, where the ordinary sea-weeds give place to nullipores and horny zoophytes, where the great scallop replaces the oyster of the laminarian zone, where the common gasteropods are *buccinum*, *fusus*, *pleurotoma*, *natica*, *aporrhais*, *fissurella*, *emarginula*, *pileopsis*, *eulima*, and *chemnitzia;* the bivalves are *lima*, *arca*, *nucula*, *astarte*, *venus*, *artemis*, *corbula*, *thetis*. But the muddy or sandy character of the sea-bed has an

[1] See Keith Johnston's Physical Atlas.

influence of its own in governing the distribution of life, at least in the littoral zone, and it is well known that genera like *litorina*, *patella*, *purpura*, *fissurella*, and *trochus* are found on rocky coasts—*cardium*, *tellina*, *solen*, *cerithium*, on sands; while *mytilus* is a lover of gravel, and *mya*, *lutraria*, *pullastra*, frequent muddy shores. It is probable that mollusca, like fishes, migrate, for frequently large numbers of dead shells are dredged without a trace of living animals.

Existing Distribution of Genera.—Any one who would become a palæontologist must be familiar with the geographical distribution of existing genera, and to this end should indicate as far as possible upon blank maps the homes of the species of each genus as they are examined. For, only when the geographical areas occupied by species are known, and considered in relation to their several distinctive characters, is it possible to estimate the geological circumstances to which the distribution is due, or the antecedent specific characters from which the attributes of living species have been evolved. The study of genera may thus sometimes aid in discovering to us changes in the distribution of land by which the species have become distributed over the world. And often when the genera of a family are compared together, and compared with their fossil representatives, the mode of origin of the genera, as well as the migrations and modifications which species have undergone, are suggested with great probability. We may illustrate this aspect of palæontology by reference to the Gasteropod genus Strombus, which dates back to the Cretaceous period, is imperfectly known from the Tertiary rocks, and is widely distributed in existing seas. This genus includes some large species in the West Indies, such as are commonly carved for cameos, and a group of small species distinctive of the Philippine Islands, besides the ordinary widely-distributed types. Some species of Strombus approach towards the allied genus Pteroceras, and others towards the allied genus Rostellaria; and among the Lower and Middle Tertiary rocks of Europe we find the blending of generic characters is more marked, and species occur which show that some of the areas from which Strombus and Rostellaria are now absent, were inhabited by those genera in comparatively late geological periods of time. So that we are compelled to believe that the uplifting of existing land has divided the species, and gathered them in affiliated groups in definite localities. The story of the Strombs, or any family, would take too much space to tell in detail here, and we can only indicate the general distribution of species. First: In the Red Sea are *Strombus gallus*, *S. fasciatus*, *S. Ruppelli*, and *S. lineatus*. *Strombus tricornis* is common to the Red Sea and the Antilles; *Strombus elegans* is common to the Red Sea and Philippine Islands; and *S. gibberulus* has a wide range from the Red Sea by the East Indies, Philippine Islands, and Moluccas to the Society Islands. On the coasts of India and Ceylon are found *Strombus Lamarckii* and *S. Sibbaldii;* but *S. fissurella* and *S. canarium* range to the Philippines, while *S. plicatus*, with the last-named species, range from India to the Moluccas. The Philippine Islands yield *Strom-*

bus alatus, also characteristic of the Gulf of Mexico. *Strombus floridus*, which ranges to the Society Islands, *S. Luhuanus*, and *S. mutabilis*, are common to the Philippine Islands and Moluccas, while the typical Philippine species comprise *S. succinctus*, *S. pulchellus*, *S. vittatus*, *S. bulbulus*, *S. crispatus*, *S. dentatus*, *S. epidromis*, *S. samarensis*, *S. guttatus*, *S. minimus*, *S. Isabella*, *S. labiosus*, *S. laciniatus*, *S. marginatus*, *S. leutiginosus*, *S. latissimus*, *S. papilio*. The *Strombus auris-Dianæ* is common to Malacca and some other parts of the coast of Southern Asia. *S. rugosus* ranges north to the Korea. *S. Japonicus* is peculiar to Japan. *Strombus urceus* ranges from the Philippines to the north of Australia, while *S. variabilis* ranges to Australia on the one hand, and Zanzibar on the other. Both these regions are small Stromb centres; the former includes, in addition to the two species already named, *S. fusiformis*, *S. deformis*, *S. Australis*, and *S. Campbelli*. New Zealand has the *Strombus Novæ-Zealandiæ*. On the Zanzibar coast, in addition to the *S. variabilis* is the *S. columba*, which probably ranges to India and the Philippines. The Mauritius yields *S. Mauritianus*, and Bourbon has *S. cylindricus*. There are at least three species at the Society Islands. *Strombus granulatus* of the Galopagos, and the *S. gracilior* of Panama, are common to St. Helena. The West Indian types include, besides species already mentioned, *Strombus Peruvianus*, *S. galeatus*, *S. pugilis*, *S. gigas*, *S. bubonius*, also found at the Cape Verd Islands, *S. accipitrinus*, and *S. bituberculatus*.[1] Thus the geographical areas of the groups of species are highly suggestive of antecedent physical circumstances governing distribution of faunas, and the student may bring this knowledge to bear in palæontological studies.

S. P. Woodward's Provinces of Marine Life.—The distribution of marine life in provinces justifies a recognition of tropical, temperate, and arctic zones. In so far as these are defined by the mollusca, we are still indebted for definition of the provinces to the work of the late Dr. S. P. Woodward.[2] He recognised eighteen marine provinces, of which the Indo-Pacific, West African, Caribbean, Panamic, and Peruvian may be accounted tropical, unless the Peruvian be included in the southern temperate with the Patagonian, South African, and Australian regions. In the northern parts of the world, warm temperate and cold temperate faunas are recognised. Thus in the Pacific the Californian and Japonic are warm temperate, and the Aleutian cold temperate, while in the Atlantic the Gulf weed divides the transatlantic province of the United States seaboard from the Lusitanian province, which extends into the Mediterranean; the colder temperate area reaches from Nova Scotia across the Atlantic, and widens out with the Gulf Stream to the north of Norway, forming the provinces which Forbes and S. P. Woodward termed Boreal and Celtic. There remains an Antarctic province, which is named Magellanic, which includes the southern part of South America; and a large Arctic pro-

[1] See Lovell Reeve: "Conchologia Iconica."
[2] "Manual of the Mollusca," 1851–1856.

vince, which extends southward with the Arctic currents to Iceland and Newfoundland in the Atlantic and the Aleutian Isles in the Pacific. These provinces may be taken to represent at least as many survivals from faunas which have been fossilised in seas neighbouring to those in which they now exist. Dr. S. P. Woodward placed upon a map some facts in the distribution of genera, which, from a philosophical point of view, are more valuable than the enumeration of species; and to this reference should be made. We now enumerate a few of the typical genera[1] of the several provinces, grouped as—(1) Arctic, (2) Temperate, (3) Tropical.

Arctic Province.—Includes Buccinum, Chrysodomus, Trophon, Admete, Trichotropis, Velutina, Lacuna, Astarte, Cyprina, which are perhaps most characteristic of the Old World; while the Arctic part of the New World includes Margarita, Crenella, Rhynchonella, Terebratella, Yoldia, Glycimeris, Solecurtus, Crepidula, Scalaria, Natica.

Magellanic Province.—This comprises many of the Arctic types, showing that the Arctic and Antarctic life are really continuous, but exist as deep-sea species in the intervening temperate and tropical areas. Among the Arctic genera common to the Magellanic province may be mentioned Chrysodomus, Trophon, Trichotropis, Margarita, Rhynchonella, Crenella, and Astarte, to which may be added Voluta, Modiolarca, and Mytilus.

Cold Temperate Zone.—*The Boreal and Celtic Provinces* represent a large part of the life which is influenced by the Gulf Stream. This circumstance accounts for the narrowness of its seaboard on the Canadian coast and its great expansion northward from the mouth of the English Channel. There is much to be said in favour of the subdivision of this region into Scandinavian, Germanic, and Celtic, and any sub-division must recognise the fact that the upheaval of Scandinavia distributed life in a different direction to that produced by the elevation of the Alpine axis. Among the typical genera of the northern part of the province are Terebratulina, Waldheimia, Trivia, Cryptodon, Panopea, with Crania, Astarte, Cyprina. The southern or Celtic part includes Patella, Litorina, Cardium, Tellina, Donax, Ostrea, Pecten, Thetis, Aporrhais.

Aleutian Region.—The corresponding Aleutian region in the Pacific presents life which may be regarded as only separated from that of the British seas by the elevation of the intervening land. It comprises the genera Panopæa, Crepidula, Chrysodomus, Purpura, Buccinum, Pleurotoma, Haliotis.

Warm Temperate Zone.—*The Californian Region* gives a good example of the life of the warm temperate region reaching almost as far south as the tropic of Cancer. Among the genera are Chiton, Patella, Haliotis, Fissurella, Cypricardia, Waldheimia.

Japonic Province.—The Japanese islands and Corea among others comprise the genera Astarte, Panopea, Conus, Terebra, Murex,

[1] Such genera may be examined in the Natural History Collection of almost any public museum, but the student would do well to obtain examples of genera for further study.

Cyprea, Haliotis, Pecten, Nucula, Crassatella, Diplodonta, Isocardia, Artemis. In latitude and in life this region represents the Lusitanian province.

Lusitanian Province.—This area includes the Bay of Biscay, the coast of Portugal, Mediterranean, and north-west coast of Africa. Among its characteristic genera are Conus, Pleurotoma, Terebra, Cassis, Triton, Vermetus, Solarium, Turbo, Haliotis, Spondylus, Avicula, Chama, Crassatella, Cardita, Cytherea, and Columbella. Among characteristic Mediterranean genera are Fasciolaria, Siliquaria, Clavagella, Thecidium, Cassidaria. The fauna includes many minor types, especially in the islands of the north-east of Africa and of the Mediterranean.

The Trans-Atlantic Province.—On the opposite side of the Atlantic, extending southward from New England to Florida, is a fauna which varies with latitude, but comprises Conus, Oliva, Fasciolaria, Avicula, Artemis, Lutraria in the south, and Nassa, Columbella, Ranella, Scalaria, Calyptræa, Bulla, Arca, and Solemya.

Southern Temperate Zone.—The warmer temperate fauna is represented south of the tropic of Capricorn, though on the Peruvian coast of America it reaches northward to near the equator. This correspondence may be taken to indicate that the life is not really severed by the intervening faunas of tropical regions, but only descends in the intervening areas to greater depths.

The Patagonian Province.—This fauna has presumably been separated from the Peruvian province by the upheaval of South America, and many characteristic living species are found far inland in raised beaches. Among the characteristic genera are—Oliva, Voluta, Terebra, Scalaria, Natica, Chiton, Solen, Lutraria, Nucula, Leda, Cytherea, Corbula, Pinna, Mytilus, Litthodomus, Pecten, Ostrea, besides some forms like Plicatula, Lucina, and Venus, of which species range to the Antilles.

South African Province.—The fauna of South Africa has much in common with that of the Indian Ocean, but very few species range as far north as the Red Sea, and fewer still to Senegal. The characteristic genera comprise Terebratella, Chiton, Patella, Fissurella, Crepidula, Trochus, Littorina, Phasianella, Turritella, Pleurotoma, Typhis, Triton, Nassa, Columbella, Mitra, Voluta, Cyprea, Conus, most of which are represented by several species.

Australian Province.—The Australian province includes the southern half of Australia, Tasmania, and New Zealand. Among the characteristic types are Struthiolaria, Trigonia, Chamostrea, Myadora, Myochama, Crassatella, Cardita, Cypricardia, Oliva, Conus, Voluta, Fasciolaria, Pandora, Terebratella, Waldheimia, and Crania. Rhynchonella is common to the Arctic Seas, and Panopea is not known nearer than Japan. Haliotis is common with Litorina on the shores of South Australia, while New Zealand yields Voluta, Strombus, Triton, Conus, Oliva, Cyprea, &c.

Peruvian Province.—Includes the Pacific coast of South America, from Callao to Valparaiso. The genera comprise Chiton, Patella,

Trochita, Crepidula, Fissurella, Tornatella, Litorina, Cancellaria, Murex, Triton, Columbella, Oliva, Purpura, Mitra, Pholas, Solen, Mactra, Venus, Crassatella, Nucula, Leda.

Tropical Zone.—There remains the large tropical region, which we imagine to be to some extent superimposed upon the temperate life.

The Panamic Province.—Here, at the mouths of the rivers, are the Potamides, Potamomya, Arca, Cyrena, Auricula, while the Litorinæ climb trees. The shells of the shore include Columbella, Cypræa, Mitra, Purpura, Cassis, Conus, Strombus, Pleurotoma, Hipponyx, Fissurella; while among shells of deeper range are many species of Murex, Monoceros, Oliva, Cancellaria, Lingula, Discina, Spondylus, Cardium, Venus, Artemis, Pandora, Pholas. The narrow land of Central America and Mexico makes a complete separation between this region and that on the American side of the Atlantic.

The Caribbean Province includes the Gulf of Mexico, West Indian Islands, and South American coast as far as Rio. It is a region fringed with coral growth. The characteristic genera include Strombus, Murex, Triton, Fasciolaria, Cancellaria, Terebra, Cassis, Columbella, Voluta, Oliva, Conus, Cyprea, Litorina, Turritella, Fissurella, Nerita, Calyptræa, Crepidula, Patella, Chama, Lucina, Venus, Cytherea, Artemis, Lima, Arca, Yoldia, Crassatella, Pholadomya.

The West African Province includes the coast within the tropics. Its genera comprise Strombus, Triton, Oliva, Purpura, Murex, Terebra, Mitra, Pleurotoma, Clavatula, Conus, Natica, Cypræa, Vermetus, Cerithium, Turritella, Haliotis, Nerita, Arca, Cardium, Artemis, Cytherea, Cardita.

Indo-Pacific Province.—This is an enormous area ranging between Australia and Japan and Easter Island in the Pacific and the east coast of Africa. This also is a region of coral reefs. A large number of the characteristic genera occur fossil in the Lower Tertiary strata of Europe. Among the tropical genera are Nautilus, Pteroceras, Rimella, Rostellaria, Seraphs, Turbinella, Ancillaria, Magilus, Neritopsis, Hemipecten, Placuna, Malleus, Vulsella, Cucullæa, Hippopus, Tridacna, Cypricardia, Anatina. Among types which are common to the American coast of the Pacific are Conus, Pleurotoma, Harpa, Mitra, Pyrula, Imperator, Lingula, and Discina. The difference between the Mediterranean fauna and that of the Red Sea is marked by some of the genera that we have named, and the abundance in the Red Sea of species of others, such as Conus, Cyprea, Mitra, Cerithium, Pinna, Chama, and Circe.

Relation of Living to Fossil Faunas.—If we compare these faunas with each other, it would be impossible to predicate from any principle recognisable in structure that some were Arctic and others tropical. They rather suggest the grouping met with in different geological formations; and it is only when we begin palæontological studies from the point of view of such faunal distribution, and trace its origin back to the development of existing continents, which laid the newest strata bare, and drove marine life from off them,

that we are able to attack the problem of identification and correlation of strata by means of the life they contain. It must be the palæontologist's endeavour to know the history of life, genus by genus, and fauna by fauna, accurately tracing distribution in time, and distribution in space, as it varied with the succession of geological ages. Hence, every fossil has a value as a member of a fauna, infinitely more important than its value as a characteristic species of a stratum; and the aim of the geologist in collecting fossils from strata is more a demonstration of the history and evolution of life, than the division of geological time into successive epochs, which have no meaning except as recording the physical history of life on the earth.

The student finds life provinces superimposed upon each other in the sequence of the strata, and soon discovers that these life provinces varied in past time with geographical distribution in a way similar to their variation on the earth's surface now; and in proportion to the fulness of knowledge of this succession and variation of life, so will be our success in converting the vertical succession of life preserved in the strata back into the horizontal distribution of geographical provinces in the seas which geological formations represent. We have no hesitation in affirming that the task is now within the student's grasp; for life provinces were clearly defined in the earliest epochs of geological history which have been discovered.

Sclater's Natural History Provinces.—To Dr. P. L. Sclater belongs the honour of having been the first to map out the division of land life into six great provinces. He recognised, as others have done before and since, the predominant influence of climate in giving a similar facies to life in the same latitude. Dr. Sclater's provinces are named Palæarctic, Nearctic, Neotropical, Ethiopian, Oriental, and Australian. These divisions do not coincide with the existing divisions of land, for Mexico and the West Indies are grouped with South America; the Ethiopian region only comprises Africa, south of the equator; while the Oriental region, in addition to the Malay Archipelago, takes in Southern China, India, and the intervening countries; while the Australian region includes New Zealand, Polynesia, New Guinea, and other islands northward.[1]

Arctic Region.—It is convenient to recognise, as does Joel Asaph Allen,[2] a small arctic realm which unites the Palæarctic and Nearctic regions. This area is characterised by the polar bear,[3] polar hare, musk ox, arctic fox, lemmings, narwhal, white whale, and walrus. It shares with the colder temperate region many seals, the reindeer, moose, and some fur-bearing carnivora and rodents.

Palæarctic Region.—The Palæarctic region, or northern zone of the Old World, includes Europe and Iceland, the Azores, Canaries, and Cape Verd Islands, Africa north of the Sahara, Asia as far as Affghan-

[1] Wallace: "Geographical Distribution of Animals."

[2] Bull. U. S. Geol. and Geog. Surv. Territ., vol. iv. p. 313.

[3] It may be useful to examine these types whenever possible in the Natural History Collections of the British Museum, or other museums; and in Zoological gardens.

istan and north of the Himalayas, and the northern half of China and Japan. This vast region, though distinguishable into warmer temperate and colder temperate portions, is essentially one province, characterised by the life ranging through it from the Pacific to the Atlantic Ocean. Most of the familiar animals of Europe range through Northern Asia; and although the distribution of wild animals has been much modified by man, the evidences of ancient distribution which are furnished by the valley gravels of the north of Europe, enable us to recognise a community between the North African life and the European life which man has exterminated. Among the more familiar mammals in this region may be named horses, asses, sheep, goats, camels, the fallow deer, red deer, roebuck, ibex, chamois, addax antelope, saiga antelope, hedgehog, mole, shrews, water shrew, desman, vole, mole-rat, beaver, squirrel, and hare, with occasional monkeys, flying foxes, bears, and the hyrax. There are 107 genera of mammals in the region, 36 of which are peculiar to it. The Mediterranean province includes 60 genera, the Manchurian province 65 genera, while 50 genera are common to the two distant regions. Eighty genera occur in the warm temperate portion, 50 in the cold temperate portion; 15 are universally distributed. The only family of birds peculiar to the province is that represented by the bearded titmouse. Of the 323 genera of birds, 128 are common to the Neartic region, and 51 genera are common to the Indian and Ethiopian regions. Thirty-seven genera are peculiar to the region, which may be grouped as warblers, babblers, fly-catchers, finches, buntings, starlings, crows, woodpeckers, sand-grouse, grouse, pheasants, duck, crane, plover, and snipe. The reptiles and amphibia include vipers, the giant salamander, the land salamander and proteus; while among fresh-water fishes there are salmon, trout, carp, pike, perch, sturgeon, and lampreys.

The Nearctic Region.—As compared with the corresponding region of the Old World, it is found that, while there is a similar richness in the cold temperate region, the warm temperate region of North America is poorer in life, in harmony with its smaller geographical extent. It contains a total of 72 genera of mammals, of which 23 are peculiar to the region. But the correspondence between the Palæarctic and Nearctic regions is found chiefly in the north temperate parts, and is indicated by such animals as dog, wolf, wolverine, sable, weasel, otter, bear, seal, deer, sheep, bison, shrew, squirrel, vole, hare; while the characteristic genera include urocyon, the skunks, cariacus, mazama, antilocapra, scalops, scapanus, neosorex, blarina, cynomys, haplodon, zapus, geomys. Only one family of birds, the chamyæidæ, is peculiar. The Nearctic birds include 330 genera, of which 24 are peculiar to the region, among which are gulls, ducks, snipe, woodpeckers, pigeons, falcons, crows, &c. Among the reptiles is the salt-water terrapin and the genus kinosternon, though some species range to Central America, and include the alligator, terrapin, chelydra, the platypeltis of Fitzinger, and the Mississippi alligator. Among fishes there are fewer cyprinoids than in the Palæarctic region. Sticklebacks are as numerous as in Europe, and the pike is well repre-

sented. Sturgeons and lampreys occur with the ganoid fishes amia and lepidosteus. The latter is found fossil in Europe.

The Neotropical Region is limited towards the north by the 22d parallel of north latitude. It includes the Galapagos Islands, the Falkland Islands, and West Indies. Mr. Allen subdivides it into two parts, tropical and temperate. The southern temperate area includes the family of Chinchillidæ, the genera Auchenia, Chlamadophorus, Myopotamus, Octodon, Ctenomys, &c. The spectacled bear is confined to it. It is divided into Andean and Pampean portions. The tropical part of the region includes three districts—Central American, Antillean, and Brazillian. This region includes all the American monkeys, howlers, woolly monkeys, spider monkeys, the capuchins, the marmosets, all the American edentata, such as the ant-eaters, armadilloes, and sloths, many of the American felidæ, and many rodents and bats. The birds are more than half passerine. The chief group is the humming-birds, which comprises 120 genera, of which only 5 are found in the Nearctic region. Other characteristic birds are the rheas, tanagers, the piculules, the ant-thrushes, together with toucans, trumpeters, screamers, &c. The region is rich in reptiles. There are the great Galapagos tortoise, the matamata, and hydromedusa; the jacare. Among lizards, the ameiva, cnemidophorus, phrynosoma, teius, heloderma, iguanas, the marine amblorhynchus; and rattlesnakes, which, however, also range farther north. The fishes all belong to nine families, and mainly to the Siluridæ (54 genera), Characinidæ (40 genera), Chromides, and electric eels. There is a close relationship to the Ethiopian fishes; and one Indian species occurs which is not found in Africa.

Ethiopian Region.—All Africa, south of the Sahara, and Madagascar, are grouped as the Ethiopian region. Mr. Allen would unite with it the Indian region, but although a connection of a remarkable kind between these regions is evidenced by the range of many genera of mammals, birds, &c., we are disposed to regard the connection as one rather belonging to the later Tertiary time than to the existing order of nature. The African region, compact as it is, includes eastern, western, and southern sections. The following types are characteristic of the African region:—The aard wolf (*Proteles*), hippopotamus, rhinoceros, the wart hogs (*Phacochœrus*), giraffes, hyrax, the lemurs, golden moles, jumping shrews, African river shrews, lophiomys, and the Cape anteater. Besides these may be mentioned the anthropoid apes, gorilla and chimpanzee, a multitude of antelopes, and various rodents. In the eastern province there are twelve peculiar genera; thirty-nine are restricted to Ethiopia, but range over more than one division of the province; thirty also occur in the Indian region. The proportion of Indian species is as well marked in the south and west. The birds are as distinctive; and, like the mammals, indicate a close affinity with Indian types. The ostrich helps to bridge over the geographical interval between the African and Indian regions, and the soft tortoises of the Old World are chiefly divided between Africa and the Indian region. The true crocodiles of both provinces may be referred to the

same genus. The monitors are best known from their African representatives, but range over India, some, indeed, reaching to Australia; and the chameleons, through having their home in Madagascar, and spreading over Africa to the south of Spain, are found in the south of India and Ceylon, reaching to Singapore. Fishes, like the other groups, pass from the African region by the valley of the Nile to Syria and South-Western Asia. Dr. Günther states that of the 39 groups of fresh-water fishes 15 are represented in the African region, though the number of species at present known is small. The best represented families are the Siluroids, Cyprinoids, Mornugridæ, Characinidæ, and Chromides. Many of the Siluroid genera, such as Clariina, Silurina, and Bagrina, are common to India, and a few to South America. One species of the genus Arius is common to Indian and African rivers, which is the case with the Cyprinoid fish Discognathus. Of ganoid types tropical Africa yields the Lepidosiren and Polypterus. The affinity with South American fishes is chiefly marked by the Chromides and Characinidæ, though for the most part the generic groups are distinct.

Oriental or Indian Region.—This region includes India, China south of the Yang-tse-Kiang, the Malay Peninsula, the Malay Archipelago, Philippine Islands, and the islands as far as "Wallace's line," which excludes Lombok, Celebes, and the islands south and east of them, but includes the island of Bali. It is continued north-east up the Strait of Macassar. In this region, in the continental part of the area, there are 94 genera of mammals, of which 43 are peculiar to the Indian region, and 28 common to the African region. The Malayan or insular part of the province comprises 83 genera, of which 25 are restricted to the province, 52 are otherwise restricted to the Indian region, and 29 are common to India and Africa. Each of the larger islands has one or two types peculiar to itself. Among the characteristic genera are the monkeys Hylobates, and Semnopithecus and Macacus; Paradoxurus, many deer, a few antelopes, chevrotains of the genus Tragulus, rhinoceros and elephants, civets, tigers, leopards, bats and flying foxes, the scaly anteaters, and a tapir. In common with Africa are the manis, porcupines, buffaloes, elephants, civet; while many genera, like bears, deer, goat, pig, hedgehog, mole, shrew, are common to the Palæarctic region. The birds include in the continental area 116 genera, of which 32 are common to the Palæartic region, though of course the community of genera does not extend to species. Among the common types are fowls and pheasants, pigeons, parrots, hornbills, woodpeckers, and sun-birds, the parrots and woodpeckers becoming more numerous in the insular part of the province. Besides the reptiles mentioned as common to the Ethiopian region, there are the shield-tailed snakes, the thorn-tailed uromastix, the dragons, the gavial; and here, as in the Ethiopian region, salamanders are wanting. The fresh-water fishes of India are found extending through Persia to the Tigris. Twelve families are represented; the species constitute two-sevenths of the known fresh-water species, of which Siluroids comprise 200 species, and Cyprinoid fishes about 330

species. Barbels are common to the Palæarctic region, as are the Mountain Barbels (Schizothorax). The Siluroid genera Clarias and Heterobranchus are common to Africa and India. The genus Symbranchus is common to India and tropical America.

Australian Region—The Australian region is limited to the north by "Wallace's line," a strait 15 miles wide. The mammals are chiefly found in Australia, Tasmania, New Guinea, and neighbouring islands. They are mostly marsupials and monotremes, with bats and small rodents. The monotremes comprise the Platypus, Echidna, and Trachyglossus. The marsupials are almost limited to this region. They parallel most of the orders of placental mammals—the wombat, *Phascolomys*, representing the Rodents, the Bandicoot *Perameles* and *Myrmecobius* being Insectivores; the grass-eaters being paralleled by kangaroos and kangaroo-rats; while the Tasmanian types, *Thylacinus* and *Sarcophilus*, with *Dasyurus*, represent carnivora; and the Plalangers and *Phascolarctos* have been termed marsupial monkeys. Among birds there are nearly twenty families peculiar to the region. These include honeysuckers, thickheaded shrikes, caterpillar-eaters, flower-peckers, and swallow-flycatchers; while the weaver birds, moreporks, kingfishers, and pigeons attain their maximum development in the province. There are many Ratitæ. Birds of paradise are found in the Papuan and Moluccan areas. In Australia are many parrots, bower birds, lyre birds; while the New Zealand region is chiefly remarkable for its living kiwi and extinct moas. The Australian lizards include the frilled lizard Chlamydosaurus, and the species of Moloch, which closely resemble Phrynosoma, the horned lizard of Mexico. The Hatteria is distinctive of New Zealand. The fishes are few, mostly of Indian types in the tropical area, with Ceratodus for the most interesting of its genera. In the south there are no fishes in the Cod family, while New Zealand has 6 genera.

Method of Palæontological Work.—Dumont, one of the greatest of physical geologists of the last generation, had a strong belief that palæontology was superfluous for geological work. It may be that it has sometimes been used with too much dogmatism and too little learning, but it is as certainly a science as physical geology, and absolutely inseparable from it. Every induction of palæontology is based upon evidence from the purely physical conditions of strata. Thus we meet with the genus Cyprina in the Lower Greensand, represented say by the species Cyprina angulata; we find it again in the Thanet sands, represented by Cyprina Morrisi and Cyprina planata, though these range on into the London clay; we meet with it next in the Cyprina Islandica of the crag, which is also a sandy deposit; and we find this species widely distributed in the seas of the north of Europe and North America, so that we are justified in inferring that Cyprina has always lived along a line of coast, and probably in water of no great depth. But although we may examine every genus in this way, and compare the species so as to satisfy ourselves concerning their descent from each other, and to determine the physical conditions under which they lived, the chief business of

the palæontologist is with faunas as a whole. And he can only discover whence they came and whither they went in the ages of geological history, by first knowing the physical history of given geological deposits, and then considering the ways in which the changes in neighbouring seas modified the life in the sea which the geological stratum represents.

We may illustrate these more complex studies by reference to the Lower Tertiary strata. First, we find that, in tracing the Cretaceous beds eastward, we come upon evidences of ancient shores and land conditions. The Maestricht strata, though formed in shallower water, may be no newer than the Norfolk chalk, and the chalk of the Danish Archipelago and Scania may be essentially a prolongation of the same deposit under conditions nearer to land; but at Aix-la-Chapelle the cretaceous sands, which may well be of chalk age, contain the rich flora of an ancient land. Hence, then, without going further for other evidence of a like kind, we may conclude that in certain parts of Europe lacustrine and littoral strata were formed contemporaneous with the English chalk. Now, if we believe these cretaceous islands to have existed throughout the Chalk period, any change of level which once more brought sediments into the seas where the chalk was formed, must be supposed to have enlarged those islands, and have made them a source for sands, such as constitute the oldest of English Tertiary strata.

The lowest of our Tertiary beds is named Thanet sands. Ninety-nine per cent. of the sand, according to Dr. Sorby, is granitic sand; the one per cent. is derived from chalk flints. Hence, we must probably look to find a range of crystalline rocks as the source of the Thanet sands. We next notice the area over which the stratum is distributed. It is not found west of a line drawn from St. Alban's to Leatherhead. It is thinner on the northern outcrop of the London basin than on the southern outcrop, where the thickness is 90 feet at Canterbury, Erith 75 feet, Charlton 55 feet, Bank of England 40 feet, Battersea 17 feet, Leatherhead 3 feet. If we cross the Channel the thickness is 90 feet at Calais, and in Belgium the stratum is well represented by the Landanien inférieur, which becomes somewhat coarser in its eastward extension. There is hence a strong probability that, as the sand was derived from a granitic source, it would be succeeded, farthest from the source in horizontal direction, by a clay. If the antecedent circumstances of the Tertiary rocks justify us in looking to Central Europe for the rocks which yielded the Thanet sands, then we should expect, when the sands thin away westward, to find that the clay which replaces them would be of the same age,—that is to say, that a clay would rest upon the chalk in the western part of the London basin and in the Hampshire basin. To the Thanet sands succeed the Woolwich and Reading beds; they are the Landanien supérieure of Belgium. They are marine sands in East Kent, but from Rochester westward give evidence of nearness to land in the mixture of fresh-water shells like Neritina, with estuarine types like Melania and Cerithium, with marine genera like Ostrea; and at Lewis-

ham fossil leaves in good preservation indicate nearness to land. This estuarine condition is found as far south as Newhaven and Arundel, and extends into France, indicating that an estuary occupied much of the region which is now the Weald, and to this source we are disposed to attribute the constant change in mineral character of the unfossiliferous sands and mottled clays which form the western part of the deposit. Hence we should not regard the marine condition of the beds as graduating into the estuarine, lacustrine, and fresh-water condition of the deposit, but rather that sediments derived from different sources, and bringing different materials, overlapped each other. The succeeding Oldhaven beds are most instructive on this point, for in East Kent they consist of sands with small flint pebbles; and as the beds are followed westward to Blackheath, the perfectly rounded flint pebbles reach a thickness of 40 feet. There can be no doubt that the chalk was denuded to form these pebbles, and that the rounding of the pebbles furnished much flint sand, such as occurs irregularly in the Woolwich beds at Reading. There is therefore reason to think that the Oldhaven beds are an extension eastward of the upper part of the strata termed Woolwich and Reading series in the Hampshire basin, and that they were accumulated, as Mr. Whitaker suggests, as a shoal at some distance from shore, but, as we believe, at the mouth of an estuary, which came through France by way of Rheims. Next succeeds the London clay. This brings us, as Professor Prestwich first pointed out, a succession of new faunas, which are at least four in number, in the eastern part of the London basin, but which are not separated from each other in the same manner in the western part of the Hampshire basin. The superposition of the London clay on the Oldhaven beds indicates, first, a depression of land, which removed from the British region the evidences of shallow-water deposits; but we find them persisting longest towards the south in the Bognor rock and lower London clay sands, showing that it was from the French direction that the underlying sands and pebble beds had been derived. After the old land of Central Europe had thus become modified, and sent down to the sea its mammals, birds, emydians, and crocodiles to become mixed with the sea-serpents and chelonian reptiles of the shore, the process of depression continued, bringing an ever-different assemblage of species into the British area of the London clay sea; and then upheaval brought back again the crocodiles and fruits, until, after a second depression and renewed upheaval, the old river, now grown larger or brought nearer, swept a luxuriant flora into the clay of what is now Sheppey and Belgium. The upheaval continuing, brought back once more the condition of dry land to the south, superimposing sands upon the London clay, in which were fossilised the leaves of such trees as yielded the fruits of Sheppey. These physical conditions, here stated in brief abstract, not only govern the distribution of life, so as to explain why the fossils change with the successive strata, but serve to demonstrate the relative differences of distribution in depth of marine life preserved in the successive strata. The Thanet sands yield a littoral fauna, but the fauna of the London clay is that of

a rather deeper sea. If sands are superimposed upon the London clay, they cannot be expected to bring back again the fauna of Thanet sands, any more than a clay newer than the London clay could be expected to repeat the London clay fauna, for the reasons which have been shadowed forth in stating the laws of upheaval of land. The palæontologist may suspect physical changes which the geologist has no proof of, but more frequently his task is to demonstrate the events which stratigraphical conditions exemplify; and in any case he must work out the physical history of the deposits before co-ordinating the faunas.

Distribution of Plants.—If plants are to be used as an instrument for research by which to investigate physical mutations and revolutions in the distribution of land and water, it is impossible to neglect their present geographical distribution. For important as are temperature, moisture, and soil in governing the diffusion of plant life, when it has reached a region of land, it is to geological changes upon the earth's surface that we look for the only agent which was capable of severing floras by the upheaval of mountains and deserts, or by the depression of seas; while the upheaval of land alone blends floras which seas previously divided. The changed distribution of plant life which the strata make known, lays before us some of the stages by which the existing floras have been distributed, defined, and evolved.

There are a few water plants like Potamogeton and Ceratophyllum demersum which range almost from pole to pole. Other species, like the Pteris aquilina, range from Lapland and the upper limits of cultivation to the banks of the Amazon. Few genera have a world-wide range; but among the most widely distributed are Lotus, Rubus, Plantago, Typha, Oxalis, Nasturtium, Gnaphalium, and Senecio. But for the most part the distribution of plants is limited by the distribution of land, and defined by climate, so that zones, such as are named tropical, temperate, and arctic, may be characterised by floras.

Bentham [1] suggests that the great botanical and zoological regions probably coincide in general disposition, but that the plant regions are older than the animal regions. There is first a northern type, secondly a tropical type, thirdly a southern type. The northern type is especially marked by its needle-leaved conifers, Amentaceæ, Ranunculaceæ, Cruciferæ, and Trifolieæ. It spreads over Europe, Northern and Central Asia, and a part of North America, but has long been divided by the Atlantic and Pacific Oceans. Asia has preserved American types in Japan, Manchuria, and the Himalayas, occasionally with identical species, but chiefly with representative species. Astragalus is equally common in both continents. But other genera, like Aster, Flox, Solanum, Eupatorium, are more numerous in America than in Eastern Asia, dwindling towards Europe. On the other hand, the European and Asiatic genera of Cruciferæ, Caryophylleæ, Loteæ, and Umbelliferæ, have but few representatives in America. In the pre-glacial period the northern flora extended far

[1] See all Bentham's addresses to the Linnæan Society, especially 1869.

north in America, and was driven southward as the glacial cold came on. The northern flora is found in the mountains of Tropical Asia as far south as India; in the Abyssinian and Cameroon Mountains in Africa; in the Andes, to the extreme south of America; and in a less striking degree in the mountains of New Zealand, Tasmania, and Victoria. This large flora has been divided by climatic zones into the Alpino-Arctic, the cool temperate, and the Mediterraneo-Caucasian or warm temperate floras.[1]

The Arctic Flora is very uniform. The birch is cultivated at Reykiavik, but the summer is too short for its growth in Greenland; yet, owing to the influence of the continental mass of land, trees flourish in Siberia as far north as 67° 30′. On the eastern border of the White Sea, lat. 65°, peonies reach a large size, and aconites grow equally well in the peninsula of Kola, lat. 64°; while on the seashore the smallest willows and herbs are found. Owing to the cold, the roots of Arctic plants do not penetrate deep, but spread horizontally; thus the Valerian capitata and Salix lanata root differently in Russia and the Arctic regions. The fossil plants of the Arctic regions can in no way be regarded as the progenitors of those now met with, for all existing Arctic plants are stunted and have relatively large leaves. Iceland possesses 450 vascular plants; the west coast of Greenland, 323; Spitzbergen, 83.[2]

The Northern Flora.—In the western part of the Old World the northern and tropical floras are widely severed by the great mountain barrier which runs east and west, as well as by the African and Arabian deserts. No tropical forms of vegetable life appear to have crossed these northern barriers. In Central Asia the floras come nearer together, and the Himalayan chain alone parts these types of life, a few representatives of the tropical group extending into the warmer valleys on the one side just as the northern life is found extending on the other side. In the extreme east this mountain chain declines, so that there is no boundary dividing the two floras, and the change from one to the other is gradual, so that in the Chino-Japanese region the northern and southern types are blended, and they form a distinct flora which has much in common with the American flora. Thus the genera of eastern North America, Illicium, Schizandra, Menispermum, Caulophyllum, Thermopsis, Podophyllum, Amphicarpæa, Apios, Penthorum, Hamamelis, Dieroilla, Phryma, Pyrularia, are represented in North-eastern Asia.

In Europe the growth of wood begins in May and ends in August, but in Siberia the larch has leaves for ten weeks only. On the Alps it grows to a greater height than any other tree. The beech marks climatic conditions in a striking way by its northern distribution. In Norway it reaches latitude 59°, passes the Swedish coast near Gothenburg, and crosses the continent from near Konigsberg to Podolia. It

[1] Grisebach: "Vegetation der Erde," 1872.

[2] Many of the plants mentioned may be studied in any botanical garden, but the collections at Kew should be consulted.

reappears in the Crimea and the Caucasus, but is absent from Russia, except in the western provinces.

The flora of France passes by gradual changes to that of Kamschatka, which reproduces closely the plant life of Northern and Central Europe. In Kamschatka the birch is dominant, and there, as in Northern Scandinavia, there is a belt of fir and larch in the middle of the peninsula, while the same species of berry-bearing plants occur in the forests; and the marshes contain the same dwarf willows. Thirty per cent. of European species of vascular plants occurs in Siberia, while only 15 per cent. of the indigenous plants of the N.E. of the United States are identical with those of Europe. The northern limit of the birch nearly coincides with trees with acicular leaves. In Siberia the larch advances beyond this limit, for it begins to grow at a lower temperature than other leafy trees. The growth of wheat coincides with limit of the oak, which forms a large forest belt in Russia from the Gulf of Finland towards the Steppes, but the Ural Mountains, low as they are, stop it from penetrating further. Grisebach thinks it doubtful whether the forest areas of the Palæarctic region can be sub-divided into restricted natural floras.

North American Forest Region.—According to Dr. Asa Gray,[1] the true divisions of the forest region are those formed by the Atlantic, the Yabloni Mountains, the Pacific, and the Sierra Nevada of North America. Of forest trees Europe has 7 genera and 17 species Coniferous; Non-Coniferous, 26 genera and 68 species. But Europe wants the characteristic types of the great Appalachian land, now forming the American Atlantic States. It has no Magnolia, Liriodendron, Asimina, Negundo, or Æsculus. It wants the characteristic leguminous trees known as locusts, honey locusts, Gymnocladus and Cladrastis. It has no Nyssa, or Liquidambar; no tree referable to the Ericaceæ; no Bumelia, Catalpa, Sassafras, Osage Orange, Hickory, or Walnut; and no Coniferæ referable to the hemlock spruce, Arbor vitæ, Taxodium, or Torreya. Most of these types have lived in Europe in past Tertiary periods of geological time. The Miocene flora, as Unger demonstrated, has remarkable resemblances to that of North America. This led him to argue that the sunken island of Atlantis of Plato might have been a geological reality, and although we are not pledged to this hypothesis when the elevation of land to the north of Europe or between America and Asia offers more probable alternatives, we still must admit that the existing forest vegetation of North America is a survival of the Miocene forests. This American flora occurs fossil round the North Pole, in Greenland, Iceland, Spitzbergen, and includes with the Magnolias, Hickories, Sassafras, and Southern Cypress, Californian trees like the Sequoias, and others, now peculiar to Japan and China, like the Ginko trees, associated with pines, maples, poplars, birches, and lindens, which Asa Gray accepts as ancestors of the American temperate flora. The vegetation

[1] Bull. U.S. Geol., and Geogr. Survey Territ., vol. vi. p. 1.

of the Pacific side of the country is altogether different from the Atlantic side. The forest trees of the Rocky Mountain region include about 50 species, many of which are tree-like shrubs. Reaching into the Mexican region are the Yucca brevifolia, the giant Cactus, a species of Pinus, Arbutus, Fraxinus, Platanus, and Quercus. A desert willow, Chilopsis, fringes the watercourses. A Texas mulberry, Morus, extends into Arizona. Among conifers the yellow pine, Pinus contorta, covers large areas. It is associated with various other pines, such as the nut pine, fox-tail pine, white pine, the Douglas spruce, and a species of Juniper known as red cedar. The mountain mahogany, Cercocarpus, is peculiar to the great basin, but the ash-leafed maple, which yields sugar from the sap, reaches to Canada and New England. The poplars, generally known as Cotton-woods and Balsam poplars, rather belong to the arid regions, where streams issue from the mountains. Oaks are conspicuously absent.

Tropical Zone.—The tropical type of life was separated at an ancient period into American and Asiatic portions. It is characterised by its gigantic Monocotyledons and Arborescent Polypetalæ.[1] Some of the palms of the Amazon have a height of one to two hundred feet, and some, like Raphia and Maximiliana, have leaves more than 50 feet long. The distinctive features of tropical forests are the tall trunks, with a crown of foliage shutting out the light, and descending aerial roots like buttresses. The silk-cotton trees are thus characterised. Below the tall forest trees is a growth of lower trees, rising to 40 or 50 feet, and below these dwarf palms, tree ferns, and herbaceous ferns. The ground is sometimes carpeted with club mosses and small flowering plants. The palms include creepers like Calamus, which grows to a length of thousand feet, and yields the rattan. The rattan canes abound in the Malay Archipelago. One of them yields the dragon's blood; another palm yields the sago; the Arenga or sugar palm, and the Areca are both Malayan types. Other characteristic tropical forms of plant life are mangroves, bamboos, screw pines, bananas, arums, sensitive mimosas, and among orchids the Oneidiums of the flooded Amazon, the Cælogynes of the swamps, and the Cattleyas, of the drier forest; the ginger-worts, which produce ginger, cardamoms, grains of paradise and turmeric, begonias, vanilla, and a multitude of ferns. Among the characteristic trees many have the trunk covered with flowers, such as the cocoa tree, and Polyalthea, one of the custard apples in Borneo. Tropical trees yield the drugs toulu, camphor, benzoin, catechu, cajuput oil, gamboge, quinine, angostura bark, quassia, the urari poison, and the upas poison. Among spices are cloves, cinnamon, and nutmeg. Among fruits, brazil nuts, tamarinds, guavas, cocoa, bread-fruit, the avocado pear, custard apple, durian, mango, mangosteen, soursop, and papaw, which are all exogenous. Among the tropical exogenous woods are mahogany, teak, sandal wood, and trees which yield log wood, brazil wood, sappan wood, india rubber, gutta percha, gum tragacanth, gum

[1] Wallace, "Tropical Nature," 1878; and Henfrey's "Botany," by Masters.

damar, copal, and lac. The abundance of ferns is so great that several localities might be mentioned with 250 to 300 species in each.

Tropical Africa is a well-defined botanical region, separated from the Mediterranean region by the Sahara desert, and divided from the Cape region by the dry district north of the Gariep. It is only along the eastern side of the continent that the tropical African flora becomes blended with the South African flora, just as there is a European character in the high mountain vegetation of Abyssinia and the Cameroons. The tropical American races found on the coast region of Western Africa are more frequently identical species than representative species. It is especially to be remarked that the tropical African flora interchanges many species with continental India, but while this has long been admitted for regions north of the equator, there are many distinct African types south of it, which have representatives in Madagascar, Ceylon, Malacca, the Malay Archipelego, and Australia. North Australia contains Mangroves, Palms, Screw-pines, Bamboos, and numerous Orchids, and the Araucarias reach to just within the tropic.

Southern Zone.—The Southern type of vegetation shows its original continuity by being abundant in Restiaceæ, Protaceæ, Ericaceæ, single-leaved Papilionaceæ and Diosmeæ, as well as by the exclusive abundance of Myrtaceæ in the Australian portion. This southern region comprises four well-marked floras—first the Andean, with Fuchsia, Calceolaria, Gautheria, Ourisia, which range along the whole chain, and penetrate through Western America, and even reach Eastern Asia on the north, while on the south the Andean genera, Caltha, Drimys, Colobanthus, Acæna, Eueryphia, Fuchsia, Gunnera, Azorella, Huanaca, Crantzia, Abrotanella, Pernethya, Gaultheria, Ourisia, are represented in New Zealand, Tasmania, or Victoria.

A warmer southern temperate vegetation is found in Mexico and California and in the Argentine States, and this type is prolonged into Southern Africa and Australia. The Mexican or California Microlotus, Hoffmanseggia, Strombocarpus, Melasma, Chorizanthe, Oxytheca, are represented in extra-tropical South America. Asa Gray and Hooker enumerate about 90 genera, with almost half the species common to the two regions. The Australian flora is another type which has some connection with New Zealand on the one hand, and extends northward into Borneo and the Indian Archipelago on the other. The tropical African genera, Cadaba, Cochlospermum, Polycarpea, Adansonia, Melhania, Zygophyllum, Cassiæ pictæ, Pterolobium, Erythrophælum are represented in Australia. Australia yields more than 400 species of Eucalyptus and many leafless Acacias; it abounds in Proteaceæ. A heath of the genus Apacris is abundant. The Acacias and Eucalyptus are absent from New Zealand, where tree-ferns, lycopods, and mosses abound, and the Kawri pine, Dammara australis, is an important forest tree. Yet the New Zealand flora has much in common with Australia; and 76 genera and 89 species are said to be common to New Zealand and South America.

The South African flora is remarkably rich and distinct, showing

some connection with Australia on the one hand, and with extra tropical South America on the other. Western Europe has its Erica, Genisteæ, Lobelia, and Gladiolus, genera characteristic of the Cape, while other European groups appear to have diverged from South African stocks, but hardly any species cross the Rhine or the Rhone, or extend beyond Britain into Scandinavia.

Succession of Plant Life.—Geological history presents, in so far as it is at present known, three types of vegetation, which correspond with epochs of time. First the Primary flora, mainly cryptogamic and coniferous; secondly the Jurassic flora, including cryptogams, coniferæ, and cycads; thirdly the Cretaceous and Tertiary floras in which the living types of exogens and endogens preponderate. The oldest known plants in Europe are described by Dr. Hicks from the slates of Corwen, under the name Berwynia: it is supposed to be Lycopodiaceous. Slightly older land-plants in the United States have been named Glyptodendron. The Silurian rocks are poor in plant remains, and the well-known Pachytheca from the Ludlow bone bed is almost the only type they yield. But with the Devonian age a remarkable group of coniferous trees with a central pith is found, together with tree ferns, Lycopodiaceous plants of the Lepidodendron type, Sigillaroid trees, and numerous Equisetaceæ; and this flora presents no essential modification during the Carboniferous Period, so that, from the point of view of land vegetation, the Devonian and Carboniferous rocks are united together by a character which divides them from the Lower Primary series.[1] It is not till we come to the Trias that a new life-province appears, as indicated by the existing type of solid-hearted coniferæ, some of which were closely allied to Araucaria, mixed with a varied succession of Cycadaceous plants. Coniferæ and cycads include 9 of the 12 genera, and 11 species of the flora of the Lower Lias; but the Inferior Oolite, especially in the estuarine shales and sandstones of the Yorkshire coast, yields a richer flora, comprising 41 genera and 130 species, among which are 53 species of ferns, 23 cycads, and 7 types of coniferæ. A cycad is found in the Oxford clay, and Yatesia, Bucklandia, and other cycads are associated with Araucarites. A species of Pinites is found in the Kimmeridge clay. But the Jurassic flora, though well preserved in some Indian and Australian localities, is still too imperfectly known to permit of it having more than a stratigraphical interest, for it is impossible to infer from it either the descent of the plants or their geographical distribution.

With the Cretaceous Period, however, and the discoveries made at Aix-la-Chapelle by Dr. Debey,[2] we meet with a new phase of plant life. Pandanus had already yielded a representative in the Lincolnshire limestone, and other Pandanaceous fruits had been found in the Neocomian beds, where Mr. Carruthers has also described the fruits of conifers. The Gault, of Folkestone, has yielded cedars, and a species of Sequoites and Pinites. The Cretaceous floras are remarkable for

[1] For enumeration of these floras see vol. ii. of this work.
[2] See Lyell, "Elements of Geology," Sixth Ed., 1865, p. 330.

their diversity. This is especially seen on comparing the plants of this epoch from the following localities—Greenland, Neidershœna in Saxony, Moletin in Moravia, Quedlinburg and Blankenburg in the Hartz, Halden in Westphalia, the sands of Aix, the Senonien of Bausset, the Santonien of Fuveau in France, the North American cretaceous flora of Nebraska,[1] and the Gelinden beds of Belgium, which latter make a transition to the Tertiary.

Thus the existence of floras well defined from each other is perhaps more evident in the Cretaceous period than in any other epoch of time. The Aix flora is said to include some 200 species, of which 67 are cryptogams, chiefly ferns, including species of Gleichenia, Lygodium, Asplenium, and 10 other existing genera. There are numerous coniferæ, some hardly separable from Sequoia, species of Araucaria, rare cycads, and Pandanus, while the familiar forms of the oak, fig, and walnut are associated with several genera of Myrtaceæ, and between 60 and 70 species of Protaceæ, some of which belong to the living genera Dryandra, Grevillia, Hakea, Banksia, Persoonia, all Australian, and Leucospermum, now found at the Cape of Good Hope. The American genera found in the Dacotah group are less numerous. Professor Leo Lesquereux enumerates Liquidambar, Salix, Populus, Betula, Myrica, Celtis, Quercus, Ficus, Platanus, Laurus, Sassafras, Cinnamonum, Diospiros, Aralia, Magnolia, Leriodendron, Menispermum, Negundo or Acer, Paliurus, Rhus or Juglans, and Prunus, an assemblage which includes all the essential arborescent types of the existing American flora, except those marked by serrate or doubly-serrate leaves. Very few of the species in these rocks have the leaves serrate. No one could recognise a great break in time between the Cretaceous and Tertiary rocks on the evidence of such floras as these.

The Lower Tertiary floras elaborated by Unger, Heer, Ettingshausen, and Mr. J. S. Gardner, F.G.S., are full of interest, as showing the change in geographical distribution which took place with altered physical circumstances. We may illustrate this by citing the floras of the London clay of Sheppey, and the immediately succeeding Bagshot sands of Alum Bay. The Sheppey flora is chiefly known from the fruits, that of Alum Bay chiefly from leaves. The Sheppey flora comprises 72 genera and 200 species, of which 7 genera are Gymnosperms, 18 genera Monocotyledons, and 43 Dicotyledons. What at the present day would be termed a sub-tropical character, is indicated by plants referable to the natural orders Musaceæ, Pandanæ, Cichonaceæ, Loganiaceæ, Sapotaceæ, Ebenaceæ, Büttneriaceæ, Sapindaceæ, &c. Among the genera of the London clay are Sequoia, Pinus, and Salisburia among conifers. The Agave, Sarsaparilla, Banana, Cardamoms, and Nipa which includes many species, are all found on the north of Sheppey. There are about 15 palms, including species of Areca, Iriartea, Livistona, Sabal, Chamærops, Trinax. The Oak and Walnut, Liquidambar, Laurel, Nyssa, and Euphorbiophyllum

[1] U.S. Geol. Surv. Territ., vols. vi. and vii. Lesquereux, Cret. and Tert. Floras.

are all present, with Cinchonidium, Strychnos, and Solanites. The Ebony is represented by species of Diospyros. Magnolia, Lotos, and Victoria Water Lilies, Melons, representatives of the Mallows, Soapworts, Eucalyptus, Cotoneaster, Almond, Plum, and a multitude of leguminous plants, do not exhaust the list. When we compare this flora with that of the Alum Bay clays, 25 genera are found to be in common. The newer deposit is the richer of the two, including representatives of 116 genera, and 274 species. Among the types in common are Conifer, Sequoia, the Palm, Sabal, Oak, Convolvulus, Walnut, Laurel, Cinchonidium, Magnolia, Lotus, Maple, Plum, Almond, and the Australian Gum-tree Eucalyptus.

The types characteristic of the Alum Bay beds are more numerous—Oaks, Elms, the Beech, many species of Ficus, Santalum, which yields the sandal wood, and Nyssa, the American sour gum tree. Laurels abound, the Daphne and Aristolochia occur; the Oleaceæ have representatives of the Olive and Ash, and the Sapotaceæ are more numerous than in Sheppey. The Verbena group, Convolvulus, Heaths, Aralia, Saxifrages, white Water-lily, Spindlewood, Buckthorn and Vines, Sumach, Pistacio, and many other interesting types are found, besides numerous leguminous forms, among which Cassia is particularly abundant. The Acacia and Mimosites are both represented.[1]

This flora has much in common with the Middle Tertiary of Greenland, Iceland, Spitzbergen, and Central Europe. And at the present day, in passing from the Mediterranean to the Levant, Caucasus, and Persia, we find representatives of Miocene genera such as Chamærops, Platanus, Liquidambar, Pterocarya, Juglans, &c. Other Middle Tertiary genera may be traced through the Himalayas, and towards China; and the Tulip tree, Liriodendron, common in the Miocene time, is found in Central China as well as in North America. Some Miocene genera, like Astragalus, are common to both continents. Others, like Eupatorium, Aster, Flox, Solanum, are more numerous at the present day in America than in Eastern Asia, and diminish westward, reaching Europe in single species.

Coal.—Wherever vegetation has accumulated in swampy localities necessary for its preservation, coal has been formed, and hence coal is of every geological age. Its formation in the Carboniferous period, and generally, was analogous to the growth of peat. Intercepted drainage killed the forest trees in districts experiencing a temperate climate, and, as in the English fens or Irish bogs, the stumps of forest trees are found beneath the vegetable growth, which was itself a soil for plants of many kinds, now imperfectly preserved. Spores of coniferous trees furnished bituminous bands. Peat, like coal, alternates with beds of clay.[2]

[1] Ettingshausen: Proc. Roy. Soc., vol. xxix. p. 388, and vol. xxx. p. 228.
[2] Geological Magazine, vol. iii., Nov. 1866.

CHAPTER XXV.

THE SUCCESSION OF LIFE IN CLASSES AND ORDERS OF ANIMALS.

The Constituents of Faunas.—When we turn from the theoretical or inductive aspect of palæontology to its stratigraphical facts, the duration in time of species and genera is found to be different in the several groups of organisms. This may be a defect in our classification by which characters of different chronological value have to be made use of in distinguishing animal types in the several orders and classes. But it may also be a consequence of the struggle for existence by which the varying collocation of representatives of different groups of animals favours the extinction of some, the unchanged survival of others, and the varied development of special types of life in definite periods of time. Absence of enemies, such as indicates to us undisturbed nutrition, is calculated to result in large physical growth and abundant increase of individuals. And then the incoming of multitudinous enemies upon races which have not been inured to the conflict is likely to exterminate such groups. Professor Owen has speculated on the way in which the advent of a higher type of life modifies the physical structure of a lower type, and is disposed to attribute the changes which converted the ancient Teleosaurian type of crocodile into the modern type of crocodile, as exemplified in larger forelimbs and other distinctive characters of the skeleton, to the advent of mammalia, which furnished a new kind of prey.[1] When the higher and lower types existed under similar conditions and as competitors, the advent of the higher type, however it might stimulate specialisation in the skeleton, would probably tend to arrest organic development in the less specialised groups of lower organic grade. We are disposed to look to this principle for an interpretation of the circumstance that fishes and amphibians of the Primary rocks, and the reptiles of the Secondary rocks, when compared with their nearest living allies, approximate to higher types, and present a more varied development than the surviving groups of the same class. Similarly, the Tetrabranchiata have given place to the Dibranchiata; and the Entomostraca have not the dominance in later times which they had in the Primary period. We are therefore disposed to urge that time will not be misspent which is used in analysing a fauna into its elements, in tracing the history of the representatives of the several

[1] Q. J. G. S., vol. xxxiv. p. 426.

Orders and Classes of which it is composed, and weighing the influence of these elements of faunas upon each other, in the light of such knowledge as is available of the zoological functions of similar groups of organisms in existing natural history provinces or regions.

We now present a brief abstract of the succession of life on the earth in geological time, with a view to direct attention to some of the principal elements in fossil groups of life. No attempt at numerical estimates of individuals or species is made; and attention is only drawn to some of the commoner generic types in the more abundant Orders and Classes in which the palæontologist may study the main facts of the succession of life.

Many of the genera mentioned are only to be found in great public collections like the museums of Universities, Colleges, and the British Museum; which are to the palæontologist what a lexicon is to the student of a language, and must be used for reference. In any case it is to be desired that, before endeavouring to grasp the grand problems of distribution, evolution, and succession of life which the strata unfold through their physical geology and their fossils, some such elementary study should be gone through as is implied in the practical examination of the generic types in the chief natural history groups which we now enumerate.

Spongia.—Sponges which occur fossil are necessarily siliceous or calcareous. The siliceous sponges are chiefly hexactinellid, having six-rayed spiculæ, or lithistid, having four-rayed spiculæ or an irregular spicular structure. The spiculæ are usually united together, and in the lithistid sponge the mesh is generally dense. Siliceous spiculæ may be replaced by calcite, peroxide of iron, and iron pyrites. Sponges are chiefly known from sandstones and limestones. They are comparatively rare in the Primary rocks, from which calcareous sponges are unknown, if we except Peronella, which appears in the Devonian, but is otherwise found only in the Secondary strata. The Monactinellid sponges are represented in the Primary rocks, though the fossil genera are few.

The oldest known sponge is *Protospongia;* it belongs to the Hexactinellid group and is found in the Menevian rocks. Other primary hexactinellid sponges are species of *Astylospongia*, *Palæomanon*, *Brachiospongia*, *Dictyophyton*, *Plectoderma*, *Protachilleum*, and the Lyssakine Hexactinellid genera *Astriospongia*, *Hyalostelia*, *Holasterella*, and *Amphispongia*. The Tetractinellids are represented in the Carboniferous rocks by the species of *Geodia* and *Pachastrella*. The Lithistid sponges of the Primary strata comprise species of *Doryderma*, *Hindia*, and *Aulocopium*. The Monactinellid sponges include *Climacospongia*, *Lasiocladia*, *Haplistion*.

With the Secondary rocks the Monactinellid sponges become more numerous; the living genus *Spongilla* occurs in the Purbeck limestone, but most of the types of this group are Cretaceous, among which may be mentioned *Dirrhopalum*, *Acanthoraphis*, and *Cliona;* the latter ranging through the Tertiary deposits. The Tetractinellid sponges are chiefly Cretaceous; and among the genera which appear in the

Upper Chalk are *Ophiraphidites*, *Tethyopsis*, *Stelleta*, *Geodia*, *Thenia*, and *Pachastrella*. The Triassic rocks have only yielded calcareous sponges, among which are *Colospongia*, *Enoplocœlia*, *Celyphia*, &c., chiefly known from the St. Cassian beds; but some genera, like *Eudia*, range through the Jurassic, and some, like *Peronella*, through the Secondary rocks. Other Lower Secondary genera are *Corynella*, which sends species to the Upper Greensand, *Eusiphonella*, *Lymnorea*, *Inobolia*, *Stellispongia*, *Diaplectia*. The Upper Secondary rocks yield *Synopella*, *Oculospongia*, *Elasmostoma*, *Raphidonema*, *Pharetrospongia*, and *Pachytilodia*.

The Lithistid sponges are numerous in the Jurassic rocks of the continent of Europe, though almost unrepresented in this country. Among characteristic genera are *Cnemidiastrum*, *Hyalotragos*, *Platychonia Placonella*, *Melonella*. The Neocomian period is barren, with the exception of a species of *Mastosia*. The Upper Greensand yields *Chenendopora*, which is also represented in the Chalk. Indeed, many genera are common to these formations, such as *Seliscothon*, *Jereica*, *Doryderma*, *Phymatella*, *Trachysycon*, *Siphonia*,[1] *Jerea*. Other genera characteristic of the Upper Greensand are *Holodictyon*, *Pachypoterion*, *Nematinion*, *Hallirhoa*, *Kalpinella*, and *Rhopalospongia*. Among the genera limited to the Upper Chalk are *Verruculina*, *Scytalia*, *Stachyspongia*, *Pachinion*, *Heterostinia*, *Aulaxinia*, *Callopegma*, *Nelumbia*, *Bolospongia*, *Thecosiphonia*, *Thamnospongia*, *Pholidocladia*, *Ragadinia*, *Plinthocella*, and *Phymaplectia*.

The Hexactinellid sponges are largely represented in the Jurassic strata of the Continent. Among them are *Tremadictyon*, *Sphenaulax*, *Platyteichisma*, *Trochobolus*, *Cypellia*, *Stauroderma*, and *Porospongia*. Of genera common to the Oolites and newer Secondary series may be mentioned *Craticularia* (which ranges up to the Chalk), *Sporadopyle* (which ranges to the Neocomian), *Verrucocœlia*, and *Toulminia* (which range to the Chalk). *Plocoscyphia* ranges from the Neocomian to the Chalk. The Upper Greensand is characterised by some peculiar types, and contains others which range to the Chalk. Among the former are *Brachiospongia*, *Eubrochus*, and *Sclerokalia*. Among the genera which appear first in the Upper Greensand and range to the Chalk are *Leptophragma*, *Guettardia*, and *Ophrystoma*. Genera limited to the Chalk comprise *Strephinia* (found in the Grey Chalk), *Pleurostoma*, *Aphrokallistes*, *Ventriculites*, *Rhizopoterion*, *Sporadoscinia*, *Plolyblastidium*, *Cephalites*, *Camerospongia*, *Callodictyon*, *Diplodictyon*, *Cœloptychium*, and *Stauractinella*.

A few sponges have been described from Tertiary strata, but among the Miocene genera of Lithistids *Siphonia*, *Jerea*, *Chenenopora*, and *Astrocladia* reappear.[2]

Dr. Hinde regards Receptaculites, Ischadites, and Sphærospongia of the Silurian and Devonian rocks as Hexactinellid sponges.

[1] Sollas, Q. J. G. S., vol. xxxiii.

[2] Many species of British sponges are figured by Dr. Hinde in his catalogue of the fossil sponges in the Geological department of the British Museum, 1883, which see. See also Zittel: *Handbuch der Palæontologie* (München u. Leipzig).

Foraminifera.—The Foraminifera are widely distributed in existing seas, occur at all depths, and in all oceans. Their living substance, though sometimes yellow or red, is of a white-of-egg-like texture, is termed sarcode, and secretes shells, which are mostly microscopic, and in many types are perforated for the passage of retractile threads termed "pseudopodia." The group is subdivided into three sections; first, the PORCELLANEA or *Imperforata*, which consists of solid white shell tissue; secondly, the ARENACIA, which are built up of grains of sand and other particles blended with their calcareous coating; third, the HYALINA or *Perforata*, which comprises the great majority of fossil forms. All three groups are closely connected by intermediate types.

The only Foraminifer yet determined in the Pre-Cambrian rocks is the large incrusting *Eozoon*. There are none certainly identified from the Cambrian rocks; but with the Silurian strata we find the existing genera *Dentalina*, *Lagena*, *Nodosaria*, and *Textularia*, which all belong to the Hyaline section. The majority of Primary types date from the Carboniferous period. Among such genera which still survive are the porcellanous *Cornuspira*, the arenaceous *Saccammina*, *Lituola*, and *Trochominina*, and the hyaline *Spiroplecta*, *Valvulina*, *Planorbulina*, *Pulvinulina*, *Calcarina*, *Amphistegina*, and *Nummulites*. Several of these types are at present imperfectly known in the Secondary strata. Among genera which are peculiar to the Carboniferous period are *Stacheia*, *Archædiscus*, and *Fusulina*, which last is also of Permian age.

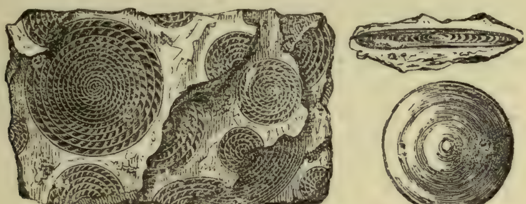


Fig. 87.—*Nummulites* (Lower Tertiary species).

With the Trias other recent types come in, such as *Miliola*, *Nubecularia*, *Dactylopora*, *Webbina*, *Bulimina*, *Lingulina*, *Frondicularia*, *Marginulina*, *Vaginulina*, *Cristellaria*, *Planularia*, *Flabellina*, *Polymorphina*, and *Globigerina*.[1] With the Lias appear the porcellanous *Orbitolites* and the Hyaline *Orbulina*. With the Oolites come in *Verneuilina* and *Spirillina*; the only new Neocomian genus is *Operculina*. The Upper Greensand introduces *Patellina*, while in the Chalk the new forms all belong to the Hyaline group. They comprise *Spiroplecta*, *Chrysalidina*, *Allomorphina*, *Ramulina*, *Pullenia*, *Sphæroidina*, *Discorbina*, *Cymballopora*, *Rotalia*, and *Polystomella*. The extinct genera of the Secondary period belong to the Arenaceous

[1] This genus has been quoted from Carboniferous rocks.

group. They include *Involutina* (found in the Lias and lower Oolite). *Endothyra* (found in the Lias), and *Parkeria* (in the Upper Greensand). *Hauerina* commences in the Gault and survives to the Middle Tertiary; *Orbitoides*, which resembles a Nummulite, commences in the Chalk and survives to the Middle Tertiary; in which the Triassic *Flabellina* also appears to becomes extinct. Other extinct Tertiary genera are *Loftusia* and *Fabularia*, of the Lower Tertiary. *Elipsodina* characterises the Upper Tertiary.

Among the Foraminifera which appear with the Lower Tertiary rocks are *Vertebralina*, *Peneroplis*, *Cheilostomella*, *Uvigerina*, *Tinoporus*, and *Heterostegina*. Some other genera appear with the Middle and Upper Tertiaries.[1]

Hydrozoa.—The Hydrozoa are for the most part unknown in a fossil state, though several jelly-fish are beautifully preserved in the lithographic slate of Solenhofen, and are to be seen in the Munich Museum. There are a few other forms like the *Palæocoryne*, which is found attached to *Fenestella* in the Carboniferous rocks of Scotland.

The entire group of graptolites is fossil in the Cambrian and Silurian strata. They have an axis, with cells arranged on one side or both sides, and these axes are variously related to each other by modes of growth. The simplest form is *Graptolithus*, or Monograptus, which has a row of cells on one side of the axis. *Didymograptus* resembles two individuals of Monograptus diverging from a common origin; *Tegragraptus* is the similar divergence of four; and *Dichograptus* the divergence of more than four graptolite-like forms from a common centre. When the Graptolite grows in a spiral, with cells on one side, it becomes *Rastrites;* when it branches in a tree-like form, it becomes *Dendrograptus*, with which may perhaps be connected the ancient *Oldhamia* of the lower Cambrian, and the *Dictyonema* of the Cambrian, Silurian, and Devonian rocks.

Diplograptus has a row of cells on each side of a straight axis like two simple graptolites back to back. Occasionally a Diprionodont form divides into two Monoprionodont branches, as in *Dicranograptus.* In another modification, four Graptolites diverge from a common axis, like two specimens of Diplograptus crossing at right angles; this type is termed *Phyllograptus* [2]

Hydrocorallina.—Louis Agassiz had referred the living *Millepora* to the Hydrozoa. This genus forms a large part of the growth of existing coral reefs, is represented in the Tertiary rocks by *Axopora*, and in the chalk by *Porosphæra*. Professor Moseley, F.R.S., has shown the allies of *Stylaster* to be hydroid;[3] it is a Miocene fossil.

In near association with these forms, *Stromatopora* of the Devonian rocks is sometimes grouped; and the Silurian *Labechia* has similar affinities.

[1] T. Rupert Jones, Catalogue of Foraminifera in British Museum. See also Carpenter, Jones, and Parker, "Introduction to the Study of the Foraminifera:" Ray Society.

[2] See Zittel, "Handbuch der Palæontologie." Lapworth Geol. Mag., 1873 and 1876.

[3] Moseley, Proc. Royal Soc., 1876.

Actinozoa.—The allies of the sea anemones are grouped into three orders, named Zoantharia, Rugosa, and Alcyonaria.

Alcyonarians are composite, and have the pinnate tentacles in multiples of four; they are represented by the living Alcyonium, which occurs fossil in the Red Crag. The sea pens are represented by *Graphularia* in the London clay; and *Pavonaria* in the Chalk. The Gorgonias are chiefly of Tertiary age; but the living *Isis* is found in the Cretaceous rocks. The Maestricht beds yield *Moltkia;* and the living *Mopsea* is first found in the London clay. The living genus Corallum dates from the Jurassic rocks. In this order of late years have been placed many genera of the Primary period, among which may be named *Aulopora*, *Syringopora*, ranging from Cambrian to Carboniferous, *Halysites*, *Thecia*, *Lyellia*, *Propora* of the Silurian, *Heliolites*, and *Plasmopora* of the Silurian and Devonian, and the Devonian *Thecostegites*. The living genus *Heliopora* dates from the Cretaceous rocks, where it is associated with *Stylophyllum*. Professor Duncan suggests that the Favositidæ, and many of the corals formerly grouped with the Tabulata, belong to this type.

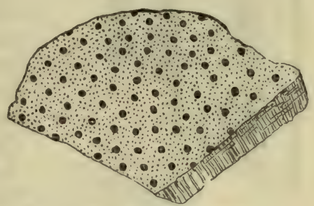


Fig. 88.—Heliolites.

Rugosa is an extinct group of corals, confined to the Primary rocks. The septa are in multiples of four; and this is expressed in Haeckel's name for the group, *Tetracoralla*. The vertical septa are combined with transverse tabulæ; frequently one of the principal septa is undeveloped, and a fossette exists in its place. The corallites of the compound coral are never connected by true cœnenchyma, being often connected by their septa or their walls, or they may be connected by lateral processes.

The larger number of corals referred to this group belong to the Lower Primary Rocks, or Cambrian and Silurian periods. Among such are *Duncanella*, *Acanthocyclus*, *Calophyllum*, *Cyathophylloides*,

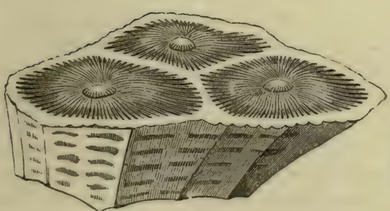


Fig. 89.—*Strombodes.*

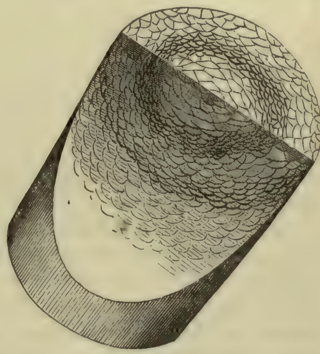


Fig. 90.—*Cystiphyllum.*

Streptelasma, *Palæophyllum*, *Siphonaxis*, *Favistella*, *Stauria*, *Microplasma*, *Fletcheria*, *Omphyma*, *Darwinia*, and the operculate corals *Goniophyllum* and *Rhizophyllum*. But many genera range up to the Devonian. Among such are *Anisophyllum*, *Ptychophyllum*, *Chonophyllum*, *Hallia*, *Aulacophyllum*, *Eridophyllum*, *Acervularia*, *Spongophyllum*, *Strombodes*, and *Cystiphyllum*, which has the septa more or less rudimentary, so that the coral is built up of vesicular tissue (fig. 90). Among peculiar Devonian genera are *Hydrophyllum*, *Combophyllum*, *Microcyclus*, *Baryphyllum*, *Metriophyllum*, *Craspedophyllum*, *Pachyphyllum*, and the operculate *Calceola*. Several genera range from the Lower Primary to the Carboniferous, and among these are *Petraia*, *Cyathaxonia*, *Amplexus*, *Zaphrentis*, *Cyathophyllum*, *Diphyphyllum*, *Clisiophyllum*, which has a central tabulate structure distinct from the external structure, and *Strephodes*. Genera which range from the Devonian to the Carboniferous include *Lophophyllum*, *Campophyllum*, and *Phillipsastræa*. Carboniferous genera include *Menophyllum*, *Phryganophyllum*, *Pentaphyllum*, *Trochophyllum*, *Caninia*, *Lithostrotion*, *Koninckophyllum*, *Lonsdalia*, *Chonaxis*, *Dibunophyllum*, *Cyclophyllum*, *Aulophyllum*, and *Michelinia*. *Polycœlia* ranges through the Primary period.

Fig. 91.—*Lithostrotion*.

The **Hexacoralla**, or *Zoantharia*, comprises two principal groups; the *Sclerobasica*, which are compound organisms, not known prior to the Tertiary rocks; and the *Sclerodermata*, which includes the majority of corals, both recent and fossil. This latter group has been divided by Professor Martin Duncan, F.R.S., into Perforata, Fungida, and Aprosa.[1]

Perforata is a type with the walls of the corallum porous or reticulate. It is largely developed at the present day, and comprises 42 genera and 5 sub-genera. In the Palæozoic rocks it is represented by *Favositipora*, which is still living. *Prisciturben*, *Stylaræa*, *Calostylis*, and *Somphopora* are Lower Palæozoic genera. *Protaræa* is Silurian and Devonian, while *Palæacis* is Carboniferous. There is no recorded Jurassic genus. The Cretaceous rocks yield *Cyclobacia* and *Actinoacis*, *Litharæa*, which ranges to the Middle Tertiary, and *Stephanophyllia*, which stills survives. *Dendracis* and *Stereopsammia* are found only in the Lower Tertiary; and the following genera commence in the Lower Tertiary, and still survive—*Ballanophyllia*, *Eupsammia*, *Endopachys*, *Dendrophyllia*, *Madrepora*, *Astræopora* and *Porites*. The Middle Tertiary yields *Lobopsammia*, and the following

[1] For Classification of the Madreporaria and Characters of the Genera, see Duncan: Journal, Linn. Soc., Zoology, vol. xviii., Nos. 104–106, 1884.

existing genera: *Terbinaria*, *Rhodaræa*, *Alveopora*. *Thecopsammia* dates from the Upper Tertiary.

Fungida is a group of corals placed by Professor Duncan between the Perforata and the Aporosa, characterised by having processes termed "synapticulæ," which cross the spaces between the septa and costæ. It has no Palæozoic representative. In the Trias the genera are *Astræomorpha* and *Omphalophyllia*. *Microsolena* is Triassic and Jurassic. *Thamnastræa* commences in the Trias, and survives till the Middle Tertiary. The Jurassic genera include *Epistreptophyllum*, *Clausastræa*, *Phragmatoseris*, *Gonioseris*, *Thamnoseris*, *Protoseris*, *Anabacia*, *Genabacia*, *Haplaria*, *Thamnaræa*, *Diplaræa*, *Disaræa*, *Dimorpharæa*, *Mycetaræa*. *Latimæandraræa* is of Corallian age. *Crateroseris* is Portlandian. The genera common to the Jurassic and Cretaceous rocks comprise *Podoseris*, *Comoseris*, *Leptophyllia*, *Cyclolites*. Among Cretaceous genera are *Mesomorpha*, *Dimorphastræa*, *Stylomæandrina*, *Micrabacia*, *Gyroseris*, *Placoseris*, *Asteroseris*, *Microseris*, *Episeris*, *Polyphylloseris*.

Dimorphocœnia is Neocomian, and *Turbinoseris* ranges from the Lower Greensand to the Lower Tertiary. *Cyathoseris* also survives to the Lower Tertiary, and *Trochoseris* and *Cycloseris* are Cretaceous genera still living. Among Lower Tertiary types may be mentioned *Polyaræa*, *Pseudastræa*, *Pironastræa*, *Reussastræa*, *Elliptoseris*, *Zittelofungia*, and *Pratzia*. *Pachyseris* and *Siderastræa* commence in the Lower Tertiary, and still survive. *Diaseris* and *Agaricia* are surviving genera, which date from the Middle Tertiary.

Aporosa.—This great group of the Madreporaria has the hard structures solid and imperforate, and the spaces between the septa are usually open, but may be closed by plates or tabulæ. This group is but poorly represented in the Primary rocks, the only genera (according to Professor Duncan) being *Battersbyia* in the Devonian, and *Heterophyllia* in the Carboniferous limestone. The Trias is characterised by *Coccophyllum*, *Koilocœnia*, and *Elysastræa*, which range to the Infra Lias. *Goniocora* and *Convexastræa* are common to the Trias and Oolites. *Stylina* and *Adelastræa* extend from the Trias to the Cretaceous. *Calamophyllia*, *Thecosmilia*, *Isastræa*, and *Latimæandra* range from the Trias to the Tertiary rocks; and *Plerastræa*, *Astrocœnia*, and *Montlivaltia* are Triassic genera, which still exist. *Trochocyathus* survives from the Lias. The genera from the Jurassic rocks include *Cyathocœnia*, *Discocyathus*, *Euhelia*, *Dendrohelia*, *Plesiosmilia*, *Pleurosmilia*, *Blastosmilia*, *Axosmilia*, *Placophyllia*, *Donacosmilia*, *Aplosmilia*, *Stiboria*, *Phyllogyra*, *Stibastræa*, *Latiphyllia*, *Phytogra*, *Lepidophyllia*, *Diplothecastræa*, and *Stylohelia*. Jurassic genera which range to the Cretaceous rocks include *Enallohelia*, *Prohelia*, *Latusastræa*, *Stylosmilia*, *Rhipidogyra*, *Pachygyra*, *Baryphyllia*, *Placocœnia*, and *Cyathophora*. *Diplocœnia* ranges from the Oolites to the Neocomian. *Trochosmilia*, *Demorphophyllia*, and *Stylocœnia* are genera of the Oolites, which survive till the Tertiary period; and the following genera from Jurassic rocks are found in existing seas, viz., *Cladocora*, *Euphyllia*, *Mœandrina*, *Symphyllia*,

Ulophyllia, *Favia*, *Heliastræa*, *Rhymastræa*, and *Stephanocœnia*. The Neocomian genera of Aporosa are *Holocystis*, *Acanthocœnia*, *Pentacœnia*, and *Brachycyathus*. *Dasmia* commences in the Neocomian, and survives till the Lower Tertiary. The Cretaceous rocks abound in Aporosa: among the genera are *Onchotrochus*, *Cyclocyathus*, *Baryhelia*, *Diblasus*, *Synhelia*, *Diploctenium*, *Peplosmilia*, *Pleurocora*, *Rhabdocora*, *Hexasmilia*, *Dactylosmilia*, *Hymenophyllia*, *Glyphophyllia*, *Eugyra*, *Meandrastræa*, *Stelloria*, *Aspidiscus*, *Stenosmilia*, *Phyllastræa*, *Placophoria*, *Stylastræa*, *Psammophora*, *Heterocœnia*, *Elasmocœnia*, *Haldonia*, *Placastræa*, and *Dictyophyllia*. Cretaceous genera which survive to the Lower Tertiary period are *Smilotrochus*, *Stylocyathus*, *Placosmilia*, *Dendrosmilia*, *Stylocora*, *Barysmilia*, *Columnastræa*, *Phyllocœnia*, and *Holocœnia*. While among genera which first appear in the Cretaceous rocks and still survive are *Caryophyllia*, *Lophosmilia*, *Diploria*, *Leptoria*, *Mycetophyllia*, *Plerogyra*, and *Hydnophora*.

Several genera of corals are peculiar to the Lower Tertiary, such as *Ceratophyllia*, *Circophyllia*, *Pattalophyllia*, *Stylangia*, *Desmocladia*, *Cyathromorpha*, *Areacis*, *Anisocœnia*, *Narcissastræa*, *Aplocœnia*, *Heterogyra*. But many genera which still survive date from the Lower Tertiary period. Among these are *Flabellum*, *Sphenotrochus*, *Placocyathus*, *Platycyathus*, *Leptocyathus*, *Paracyathus*, *Ceratotrochus*, *Amphelia*, *Oculina*, *Stylophora*, *Asterosmilia*, *Asterangia*, *Solenastræa*, and *Plesiastræa*. The Middle Tertiary genera comprise *Astrohelia*, *Haplohelia*, *Lithophyllia*, *Bathangia*, *Cladangia*, *Teleiophyllia*, *Monticulastræa*, *Favoidea*, *D'Archiardia*, *Antillastræa*, and *Diplothecastræa*.

Genera which commence in the Middle Tertiary, and still survive, include *Conocyathus*, *Deltocyathus*, *Cœnocyathus*, *Lophohelia*, *Dichocœnia*, *Echinopora*, and *Desmophyllum*. In the Upper Tertiary *Eusmilia* is found.

Asteroidea.—The true star-fishes are characterised by having the digestive and ovarian organs contained within the arms. An attempt has been made to classify star-fishes by the arrangement of the ambulacral organs into those with four rows, those with two rows, and those in which ambulacral plates separate the pores; but none of these groups are natural, and the only scientific division of star-fishes furnishes no palæontological characters.

Fig. 92.—*Palæaster.*

The oldest fossil star-fishes are found in the Cambrian rocks, *Palæaster*, *Urasterella*, and *Palæasterina* being common to the Cambrian

and Silurian. Among the genera peculiar to the Silurian, and chiefly of Wenlock and Ludlow age, are *Palæodiscus*, *Lepidaster*, *Trichotaster*, *Rhopalocoma*, *Bdellacoma*, and *Palæocoma*. The Devonian star-fishes are *Aspidosoma*, *Archasterias*, *Helianthaster*, *Xenaster*. The Carboniferous limestone has yielded no peculiar genera except *Schœnaster*, and the forms named *Calliaster* and *Cribellites*. The Triassic types are *Pleuraster* and *Trichasteropsis*. The Lias yields *Astropecten*, *Goniodiscus*, *Luidia*, *Solaster*, and *Uraster*, which still survive, together with *Tropidaster* and *Plumaster; Sphæraster* is Jurassic. The living genus *Oreaster*, common in the Chalk, commences in the Upper Oolites. *Coulonia* is Neocomian, and the living genus, *Rhopia*, is first found in beds of that age. *Arthraster* is peculiar to the Chalk. *Astrogonium* and *Stellaster* are first found in the Cretaceous Rocks. Very little is known at present of Tertiary star-fishes.[1]

Ophiuroidea.—The Brittle stars are a remarkable group of Echinoderms, having the viscera excluded from the arms, which suggest much the same relation to the Cystideans and Crinoids that ordinary star-fishes exhibit to Echinoidea. They comprise two principal types: first, that of *Euryalus*, and secondly, that of *Ophioderma*. Both these groups are known in a fossil state; the former, by *Eucladia* from the Ludlow

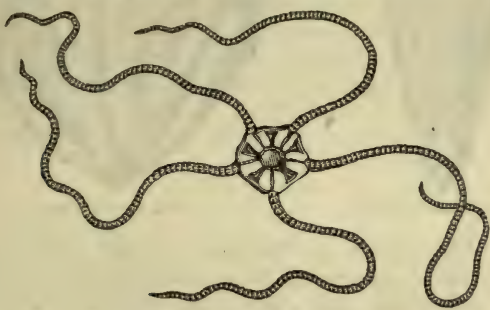


Fig. 93.—*Ophioderma.*

rocks of England, and *Onychaster* from the Carboniferous rocks of America. Professor Quenstedt has indicated a representative of the group in the Lias.

The Ophiuroid star-fishes are represented in the Primary rocks by *Protaster*, which is of Silurian and Devonian age in Europe. *Tœniaster* is of Cambrian age in Canada, and *Eugaster* is an American-Devonian genus. The existing genus *Ophioderma* dates from the Muschelkalk, and is well known in the English Lias. *Aspidura* is a characteristic Triassic genus. The Oolites yield *Ophiurella* and *Geocoma*. *Ophioglypha* dates from the Lias, and is believed to include species which have previously been referred to many genera.

Crinoidea.—The Crinoids, or sea-lilies, are an order of Echinoderms in which a jointed column supports a more or less complex cup

[1] See Wright in publications of the Palæontographical Society.

or calyx, surrounded by well-developed arms, which recall the arms of a star-fish, or the branching arms of *Euryalus*. Some types have the calyx covered with plates, and then the base of the calyx is commonly formed by five plates; the genera with a single basal plate usually have the calyx open above (fig. 99*a*). Crinoids are numerous in the Primary rocks, and less common in the Secondary strata. They are now verging on extinction, though several genera still survive, such as *Pentacrinus*, *Conocrinus*, *Bathycrinus*, *Hyocrinus*, and *Holopus*.

The oldest known genus is *Dendrocrinus* from the Tremadoc rocks. The Llandeilo beds yield *Glyptocrinus*, *Cyathocrinus*, *Rhodocrinus*, and *Actinocrinus*, the last three surviving till the Carboniferous. In America Crinoids are more numerous in the Cambrian period, and comprise *Hybocrinus*, *Anomalocrinus*, *Homocrinus*, *Cupalocrinus*.

The Wenlock period is remarkably rich in Crinoids, especially in the families represented by *Cyathocrinus*, which ranges to the Permian; *Taxocrinus*, *Ichthyocrinus*, *Cheirocrinus*, *Habrocrinus*, and *Poteriocrinus*, which range to the Carboniferous, and such peculiar genera as *Crotalocrinus*, *Carpocrinus*, *Briarocrinus*, *Dimerocrinus*, *Periechocrinus*, *Corymbocrinus*, and *Pisocrinus*. Several genera, like *Eucalyptocrinus*, survive to the Devonian. The Devonian Crinoids are also numerous. They comprise *Cupressocrinus*, *Symbathocrinus*, *Rhipadocrinus*, *Gasterocoma*, *Culicocrinus*, *Dolatocrinus*. In the Carboniferous limestone Crinoids are particularly abundant, sometimes forming the entire mass of the rock. A large number of species belong to such genera as *Poteriocrinus*, *Platycrinus*, and *Actinocrinus*, or to sub-genera grouped under these types. Other genera characteristic of this period are *Woodocrinus*, *Agassizocrinus*, *Dichocrinus*, *Ollocrinus*, *Graphiocrinus*, *Onychocrinus*. In the Dyas, or Permian, the only Crinoid is *Cyathocrinus*, already mentioned.

Fig. 94.—*Cyathocrinus.*

Fig. 95.—*Taxocrinus.*

The Trias is characterised by *Encrinus*, which belongs to the articulate sub-order, in which all the secondary Crinoids find a place. In this formation *Pentacrinus* appears for the first time, though it attains its most remarkable development in the Lias. *Cotylederma* is Liassic.

The Jurassic genera comprise *Eugeniocrinus*, *Triacrinus*, *Phyllo-*

crinus, *Plicatocrinus*, *Apiocrinus*, *Millericrinus*, *Solanocrinus*; together with *Antedon*, *Actinometra*, and *Saccocoma*,[1] the former of which still survive, and the last ranges to the Chalk.

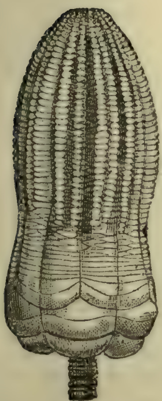


Fig. 96.—*Encrinus*.

Fig. 97.—*Pentacrinus*.

Fig. 98.—*Bourguetocrinus*.

Another cretaceous genus is *Torynocrinus*. *Bourguetocrinus* (fig. 98) ranges to the Tertiary. *Marsupites* and *Uintacrinus* are also cretaceous. The Tertiary Crinoids almost all belong to existing genera.

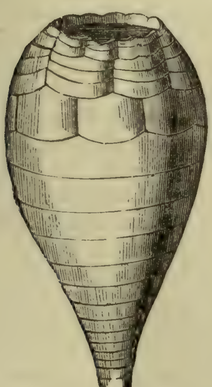


Fig. 99.—*Apiocrinus*.

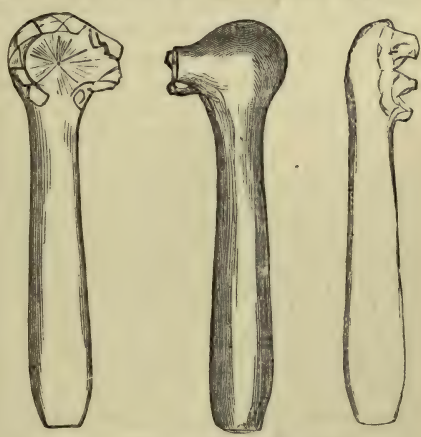


Fig. 100.—*Torynocrinus*.[2]

Cystoidea are an extinct group of Echinoderms limited to the Primary rocks. They have a more or less globular body formed of

[1] See P. H. Carpenter, Q. J. G. S., vol. xxxvi.–viii.
[2] An. Nat. Hist., March 1866.

plates; it is supported upon a short jointed column like that of the Crinoids (which is absent in *Protocrinus*), and in many genera arms are developed which are comparable to those of Crinoids. There are ambulacral furrows, which are sometimes forked, and peculiar organs termed "pectinated rhombs."

The oldest known genera are *Protocystites*, of the Menevian beds, and *Macrocystella*, which is also of Cambrian age. Other genera occur in the primordial rocks of Bohemia and the Fichtelgebirge, and *Palæocystites* is found in strata of the same age in Canada. By far the larger number of Cystidians is found in the Middle and and Upper Cambrian rocks of the Continent. *Echinosphærites* occurs in the British Llandeilo rocks, but in Russia the following genera also occur—*Sphæonites*, *Caryocystites*, *Cystoblastus*, *Asteroblastus*, *Blastoidocrinus*, and *Mesites*. Several genera occur in Sweden, such as *Eucystis*, *Holocystites*, *Glyptosphærites*, *Glyptocystites*, *Gomphocystites*, and *Lepadocrinus*. Bohemia yields *Trochocystites* and *Rhombifera*, while from the Canadian rocks many other genera are described, such as *Pleurocystites*, *Comarocystites*, *Amygdalocytes*, *Malocystites*, &c. The true Silurian rocks contain *Ateleocystites* and *Lepadocrinus*. Both date from the Cambrian rocks, and the former survives the Devonian. These, with *Primocystites* and *Echinoencrinus*, are well-known Dudley fossils. In North America, *Caryocrinus*, *Callocystites*, *Holocystites* are also found of this age. The Devonian strata yield *Tiaracrinus* and *Echinocystites*, which is also found in the Silurian rocks of America. *Agelacrinus*, which commences in the Cambrian, survives to the Carboniferous, in which *Lepadocrinus* and the embryonic crinoid *Hypocrinus*[1] are also found. After the Carboniferous period Cystidians are unknown.

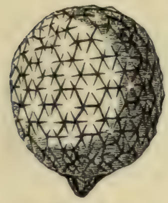


Fig. 101.—*Echinosphærites.*

Blastoidea.—The Blastoidea is an extinct order limited to the Primary rocks closely related to the Crinoidea and Cystoidea, which it resembles in having a jointed column. Its test is made up of polygonal plates; there are large ambulacral areas but no arms. Mr. Herbert Carpenter considers the type genus Pentremites to be absent from the British rocks. The group first appears in the Silurian strata of Tennessee, but is chiefly characteristic of the Devonian and Carboniferous periods. Pentremites, Nucleocrinus, and Eleutherocrinus are characteristic of the Devonian rocks, but Granatocrinus and Codonaster are common to the Devonian and Carboniferous.

Echinoidea.—The ancient sea urchins of the Primary rocks are mostly distinguished by the shell being composed of more than twenty rows of plates, with five or ten perforated plates in the apical disc. These characters have been thought sufficient by Zittel to separate the *Palæechinoidea* from the *Euechinoidea*, in which the skeleton is formed of ten rows of ambulacral plates in five pairs, alternating with five pairs of interambulacral plates, and the apical

[1] See P. H. Carpenter, Q. J. G. S., vol. xxxviii.

disc has never more than four or five perforated plates. The Palæechinoidea comprise the *Cystocidaris*, formerly described as Echinocystites by Wyville Thomson. It is found in the Silurian rocks. *Bothriocidaris* is a genus from the Cambrian of Russia, in which there are only fifteen rows of plates in the test, one interambulacral row dividing four rows of ambulacral plates. The *Perischoechinidæ* are distinguished by having more than two rows of plates in each interambulacral area. The group is almost entirely of Carboniferous age, and includes such genera as *Lepidocentrus* and *Xenocidaris* from the Devonian, *Pholidocidaris*, *Perischodomus*, *Rhoechinus*, *Palæchinus*, which has a Silurian species; *Melonites*, *Oligoporus*, *Protoechinus*, *Archæocidaris*, *Lepidocidaris*, *Lepidechinus* are common to Carboniferous and Devonian, and *Eocidaris* is Permian.

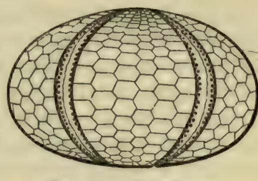


Fig. 102.—*Palæchinus.*

The ordinary sea-eggs are divided into the regular and irregular types. The regular forms, usually termed "Endocyclica," commence with the Secondary rocks. *Cidaris* dates from the Trias. This genus has been subdivided into many sections, some of which have a palæontological value. Thus *Rhabdocidaris* is characteristic of the secondary rocks; *Diplocidaris* and *Polycidaris* belong to the Oolites. *Temnocidaris* is found in the Upper Chalk. *Echinothuria* is a flexible sea-urchin, in which the plates overlap like those of the oral disc of a *Cidaris*. It is only known from the Chalk, and is represented at the present day by *Phormosoma* and *Asthenosoma*, or *Calvaria*. The Salenia type commences in the Lias with *Acrosalenia*, which survives to the Neocomian. It becomes accompanied in the Upper Oolites by *Pseudosalenia* and in the Upper Greensand by *Goniophorus* and *Heterosalenia*, and the still surviving genera *Salenia* and *Peltastes*. The great family of the Diadematidæ commences in the Trias with *Hypodiadema*, is succeeded in the Lias by *Diademopsis* and *Microdiadema*. In the Lower Oolites appear *Pseudodiadema*, which ranges to the Chalk, and *Hemipedina*, which ranges from the Oolites to the Neocomian. *Pedina*, *Hemipygus*, *Glypticus*, *Acropeltis* are characteristic of the Upper Oolites. *Hemicidaris* and *Acrocidaris* both range to the Neocomian, and *Hemicidaris* is also found in the Chalk; under the name of *Hypodiadema* it is known from the Permian and Trias. The Neocomian genera, which are common to the Jurassic rocks, include *Magnosia* and *Pseudocidaris*. *Cyphosoma* is common to the Neocomian and Cretaceous; and one species is found in Japanese seas. Among cretaceous genera are *Codiopsis*, *Echinocyphus*, *Leiosoma*, *Leiocyphus*, *Glyphocyphus*, and *Heterodiadema*. The Tertiary rocks yield several genera, among which *Echinopsis* and *Hebertia* are in the Lower Tertiary, and others, like *Temnechinus*, *Temnopleurus*, and the Cretaceous genus *Cottaldia*, survive to existing seas. *Cœlopleurus* is a Lower Tertiary type, which still survives.

The Echinidæ appear in the Lower Oolites with *Echinodiadema*,

Pseudopedina, *Stomechinus*, *Polycyphus*, of which only *Stomechinus* survives to the Neocomian, in which the living genus *Psammechinus* is found, together with *Pedinopsis*, *Glyptechinus*, and *Codechinus*. The cretaceous types are *Micropedina* and *Diplotagina*. The Lower Tertiary genera are *Echinopedina* and *Leiopedina*, while *Echinus* and many other surviving genera date from this period.

The irregular sea-urchins called *Exocylica*, in which the two poles are not opposite, have a similar range in time. Among them *Pygaster* commences in the Lias, and ranges to existing seas, accompanied by *Holectypus* as far as the Neocomian. *Pileus* characterises the Upper Oolites, *Discoidea* ranges from the Neocomian to the Chalk, *Galerites* is typically Cretaceous. *Conoclypus* commences in the Chalk, and has one existing representative.

The Euclypeasters commence in the Cretaceous beds with *Echinocyamus*, which characterises the Tertiary, and is still living. It is associated with *Fibularia*. Lower Tertiary genera include *Sismondia*, *Scutellina*, and *Lenita*. *Clypeaster* and *Lagamum* first appear in the Lower Tertiary.

The Scutelline urchins commence with the Tertiary, and are represented by the extinct genus *Mortonia*, and by species of *Scutella*, *Amphiope*. We then pass to the urchins in which an elongated form replaces the hitherto circular base, and in which both poles depart more or less from the central position. The *Cassidulidæ* present two types—first, that of *Galeropygus*, which appears in the Lias, and ranges through the Oolites, in which it is accompanied by *Hyboclypus*, *Galeroclypus*, and *Infraclypeus*. *Pyrina* commences in the Lower Oolite, and survives to the Lower Tertiary. *Echinoneus* is found in the Middle Tertiary, and still exists. The closely allied group of *Echinolampidæ* commences with *Clypeus* in the Lower Oolite, and in the Middle Oolite are found *Nucleolites* and *Pygurus*, which range up to the Neocomian, unless the living genus *Nucleolites* prolong it to existing seas. *Catopygus* is a Neocomian type, which is still living. *Cassidulus* commences in the Cretaceous, and is found in the Tertiary. Other Tertiary genera are *Echinolampas* and *Rhynchopygus*, which are still living. *Collyrites* appears with the Lower Oolite, and survives to the Neocomian. The *Ananchytidæ* begin in the Neocomian with *Holaster*, which survives to the Middle Tertiary. Other Cretaceous genera are *Cardiaster*, *Infulaster*, and *Hemipneustes*. *Ananchytes* survives from the Chalk to the Middle Tertiary. The *Spadangidæ* are represented in the Neocomian by *Heteraster*, *Toxaster*, and *Enalaster*. The Cretaceous rocks yield *Hemiaster*, *Epiaster*, *Micraster*, and *Prenaster*. The Lower Tertiary are characterised by *Macropneustes*, *Peripneustes*,

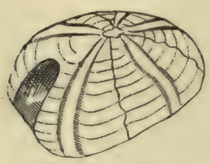


Fig. 103.—Nucleolites.

Fig. 104.—Ananchytes.

Cyclaster, while many genera still survive, such as *Schizaster*, *Brissus*, *Eupatus*, *Spatangus*, &c.[1]

Crustacea.—The Crustacea enumerated by Dr. Henry Woodward as British fossils comprise 197 genera, of which 108 are referred to the Malacostraca. The stalk-eyed group includes 53 genera, and the sessile-eyed group 53, of which 51 are trilobites.[2]

The history of the highest group, or crabs properly so called, is very imperfectly known. It commences in the Great Oolite with the genus *Prosopon*, which ranges to the Coral Rag. *Palæinachus* is another Oolitic genus found in the Forest Marble; but with these exceptions, most crabs from Secondary Strata belong to the Cretaceous beds; they are of small size. *Diaulax*, *Etyus*, *Aurithopsis* are common to the Gault and Upper Greensand. *Necroscarcinus* ranges from the Gault to the Chalk marl. *Palæocorystes* ranges from the Gault to the Lower Tertiaries. The distinctive Upper Greensand genera are *Cyphonotus*, *Eucorystes*, *Hemiono*, *Plagiophthalmus*, *Trachynotus*, and *Xanthosia*. *Platypodia* is peculiar to the Lower Chalk. There is a considerable fauna of crabs from the London clay, comprising *Cyclocorystes*, *Campylostoma*, *Goniochele*, *Gonioxypoda*, *Litoricola*, *Necrozius*, *Œdisoma*, *Plagiolophus*, *Portunites*, *Rachiosoma*, *Xanthilites*, and *Xanthopsis*.[3] The Anura are only known from two genera—*Homolopsis* from the Upper Greensand and Gault, and *Dromolites* from the London clay.

The Lobster tribe is first known in the Coal-measures, where it is represented by the genera *Anthrapalæmon* and *Palæocrangon*. The Lias yields *Æger*, *Eryon*, *Palinurus*, *Tropifer*, *Scapheus*, *Pseudoglyphæa*, and *Penæus*. *Eryma* is common to the Lias and Lower Oolites. *Glyphæa* ranges from the Lias to the Upper Greensand. *Mecochirus* is found in the Oxford and Kimmeridge clays. *Callianassa* ranges from the Kimmeridge clay to existing seas. *Astacodes* and *Astacus* are quoted from the Speeton clay. *Meyeria* is common to the Speeton clay and Lower Greensand. *Mithracites* is found in the Lower Greensand. *Hoploparia* ranges from the Lower Greensand to the London clay. *Scyllaridia* extends from the Gault to the London clay. *Mesocragnon* is peculiar to the Gault; *Phlyctisoma* is peculiar to the Upper Greensand. The Chalk yields *Enoploclytia*. In the London clay are found *Archæocarabus*, *Mithracia*, *Thenops*, *Trachysoma*. The Stomopods are only represented by *Pygocephalus* in the Coal-measures. The Isopods commence with *Præarturus* in the Old Red Sandstone. *Palæga* is from the Chalk. The living Parasitic genus *Bopyrus* dates from the Upper Greensand. *Archæoniscus*, which resembles the living Sphæroma, is peculiar to the Purbeck

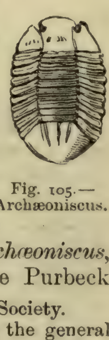


Fig. 105.—Archæoniscus.

[1] Wright: "British fossil Echinodermata:" Palæontographical Society.

[2] See Salter and Woodward: Chart of Fossil Crustacea. For the general structure of the several ordinal groups reference may be made to Huxley's "Anatomy of Invertebrates and Vertebrates."

[3] Bell in Palæontographical Society. See also Dana: "Geographical Distribution of Crustacea."

beds; but is represented in the Lower Tertiary of Garnet Bay by *Eosphæroma.*[1]

Trilobites.—Trilobites are the most distinctive fossils of Primary rocks. Like other crustacea, they go through a metamorphosis, and develop their characters as the test is shed.[2] They are mostly confined to the Cambrian and Silurian strata. The only genera which exist in the Carboniferous rocks are *Brachymetopus*, *Griffithides*, and *Phillipsia*. *Bronteus* is characteristic of the Devonian; *Cheirurus* ranges from the Tremadoc to the Devonian; *Harpes* has a similar range; and *Phacops* and *Homalonotus* extends from the Arenig to the Devonian. *Dalmannia* is the only genus peculiar to the true Silurian rocks, though *Proetus* and several genera survive to them. Thus, *Acidaspis* ranges from the Llandeilo to the Ludlow; *Ampyx* from the Tremadoc to the Ludlow; *Calymene* from the Arenig to the Ludlow; *Cyphapsis* from the Llandeilo to the Ludlow; *Eucrinurus* from the Bala to the Ludlow. A few genera reach no farther upward than the Wenlock rocks, and are wanting in the Ludlow. Among such are *Illænus*, which commences in the Arenig; and *Lichas* and *Sphærexochus*, which commence in the Llandeilo. *Trinuncleus* stops short of the Upper Llandovery, and begins with the Arenig. Among the Bala forms are *Amphion*, *Cybele*, *Staurocephalus*, and *Stygina*.

Fig. 106.—Illænus.

Fig. 107—Lichas.

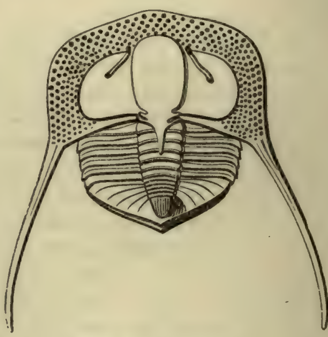


Fig. 108.—Trinucleus.

The Llandeilo period includes *Eccoptochile* and *Cyphoniscus*. It has, in common with the Arenig rocks, *Æglina* and *Barrandia*. Peculiar to the Arenig are *Dionide* and *Placoparia*. The Tremadoc trilobites include *Psilocephalus*, *Niobe*, *Neseuretus*, and *Angelina*. *Ogygia* commences in the Tremadoc, and ranges to the Llandeilo; *Asaphus* commences in the Tremadoc, and ranges to the Bala beds. Several genera are common to the Lingula Flags and Menevian beds, such as *Paradoxides*, *Holocephalina*, and *Anopolenus*. Among Mene-

[1] See H. Woodward, Q. J. G. S., May 1879.

[2] C. G. Walcot, Bulletin of the Museum of Comparative Anatomy at Harvard College, vol. viii., No. 10, 1881. Barrande, "Système Silurien de la Bohème." Salter and Woodward in Palæontographical Society, &c.

vian genera are *Arionellus*, *Carausia*, *Erinnys*. *Olenus* and *Microdiscus* characterise the Lingula Flags, *Dikelocephalus* ranges from the Lingula

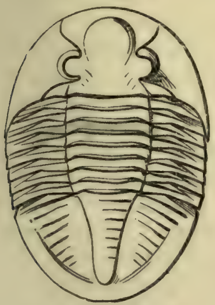


Fig. 109.—Asaphus.

Fig. 110.—Agnostus.

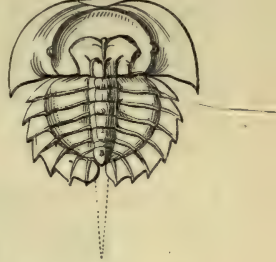


Fig. 111.—Prestwichia.

Flags to the Tremadoc. The Harlech grits yield *Plutonia*, *Palæopyge*, and *Agnostus*, which latter ranges to the Llandeilo rocks.

Xiphosura.—*The King Crabs* commence with *Neolimulus* in the Ludlow rocks; *Prestwichia* (fig. 111) and *Bellinurus* are found in the Coal-measures; but the group is absent from the newer English strata, though *Limulus* is well represented in the lithographic slate of Solenhofen.

Merostomata.[1]—*The Merostomata* comprise an allied group of Crustacea, in which the abdominal segments remain separated as among trilobites, but the appendages round the mouth are developed after the plan of the King Crabs. *Hemiaspis* is found in the Wenlock and Ludlow, *Slimonia* in the Ludlow rocks, *Stylonurus* and *Pterygotus* in the Ludlow and Old Red Sandstone, while *Eurypturus* ranges from the Ludlow to the Carboniferous limestone.

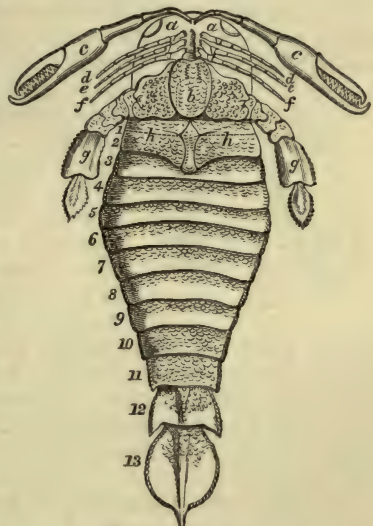


Fig. 112.—Pterygotus.
Restored by Dr. Henry Woodward, F.R.S.
a. eyes; *b.* post-oral plate; *c.* antennulæ; *d.* antennæ; *e.* mandibles; *f.* maxillæ; *g.* swimming feet; 1–12 segments, 13 telson.

The Phyllopods are mostly small crustacea with a carapace often formed of two parts. They are characteristic fossils of the Primary rocks. *Hymenocaris* is found

[1] Henry Woodward: Palæontographical Society.

in the Lingula flags, *Lingulocaris* in the Tremadoc slates, *Cariocaris* in the Arenig. *Ceratiocaris* ranges from the Tremadoc to the Carboniferous, *Peltocaris* from the Llandeilo to the Wenlock, *Dithyrocaris* from the Ludlow to the Carboniferous, *Leaia* is characteristic of the British Carboniferous strata, and the living genus *Estheria* is found in the Devonian and all newer strata, especially Triassic.

Fig. 113.—Hymenocaris.

The Ostracods are bivalve crustacea of small size, which are especially numerous in the Primary rocks. Among the oldest types, *Leperditia* extends from the Harlech rocks to the Carboniferous. *Beyrichia* ranges from the Arenig to the Coal, *Primitia* from the Llandeilo to the Carboniferous, *Æchmina* and *Thlipsura* are Wenlock; *Cytherellina* is also Silurian. *Moorea* ranges from the Ludlow to the Lias, *Entomis* from the Silurian to the Carboniferous, *Entomidella* is Menevian. The Carboniferous period has many peculiar genera. Among them are *Carbonia*, *Cyprella*, *Cypridella*, *Cypridellina*, *Entomoconchus*, *Offa*, *Rhombina*, and *Sulcuna*. But among other genera which commence in the Carboniferous and survive to the present time, may be mentioned *Bairdia*, *Candona*, *Cypripina*, *Philomedes*, and *Polycope*. *Kirkbia* is common to the Carboniferous and Permian, *Cytherideis* commences in the Permian, and still survives. *Cythere* is a living genus, which begins in the Lias. *Cypridea* characterises the Purbeck and Wealden. *Cytheridea* and *Cytherura* begin in the Gault, and still survive; *Cytherella* and *Macrocypris* are found in the Chalk and Tertiary. The recent genus *Loxoconcha* begins in the Crag.

Fig. 114.—Beyrichia (enlarged).

Fig. 115.—Cypridea.

The fossil Cirripedes belong to but few types. *Turrilepas* characterises the Wenlock limestone; *Scalpellum* survives from the Lower Greensand, *Pollicipes* from the Rhætic beds; *Verruca* survives from the Chalk, *Lauricula* is peculiar to the Chalk, *Coronula* is found in the Red Crag, while *Balanus* survives from the Headon beds of the Isle of Wight.[1]

Vermes.—The large group of worms is imperfectly represented in the strata. Many are only known from their jaws, and they have been for the most part described by Dr. G. J. Hinde in various members of the Primary rocks. Other tubicolous types occur with them, such as the Cambrian *Conchicolites*, *Spirorbis*, and *Ortonia*, which range from the Cambrian to the Carboniferous. *Cornulites*, *Serpulites*, and *Trachyderma* are Silurian. *Genicularia* is Jurassic. The living *Serpula* commences in the Trias, *Terebella* in the Lias, *Ditrupa* in the Cretaceous. Several errant worms are recogisable in

[1] H. Woodward, Catalogue of Crustacea in the British Museum, 1876.

the lithographic slate of Bavaria, and have been named *Lumbriconerites*, *Ischyracanthus*, *Meringosoma*, *Ctenosolex*, and *Eunicites*, the last being found also at Monte Bolca. Numerous genera have been described from rocks of all ages, but many of them are of uncertain affinity, such as *Scolithus*, *Arenicola*, *Histioderma*, *Ortonia*, *Scolicoderma*, &c., which are well-known fossils of the Cambrian rocks.

Bryozoa.—Bryozoa are compound organisms, which form colonies, and often encrust other organisms. They are found in the Primary rocks represented by genera which for the most part are extinct. *Phyllopora*, *Polypora*, *Fenestella* range through the period. *Ptilodictya* and *Penuiretipora* are common to Silurian and Devonian. *Pœtniopora* is Devonian, *Hippotha* and *Stomatopora* commence in the Silurian, and still exist; *Monticulipora* ranges from the Silurian to the Carboniferous. The Carboniferous genera are *Chœtetes*, *Archimedes*, *Ptilopora*, *Coscinium*, and *Ichthyorhachis*. In the Permian is found *Acanthocladia*. *Ceriopora* is a Palæozoic genus well known in the Secondary strata. Many genera commence in the Jurassic epoch, and still survive. Among them are *Diastopora*, *Berenicia*, *Defrancia*, *Reptotubigera*, *Spiropora*, &c., while *Heteropora*, *Terebellaria*, and some others are common to the Jurassic and Cretaceous periods. The Cretaceous types comprise *Hornera*, *Idmonea*, *Tubulipora*, *Discosparsa*, *Frondipora*, *Fasiculipora*, *Vincularia*, *Myriozoum*, *Cupularia*, *Lunulites*, *Retepora*, *Flusterella*, *Eschara*, *Membranopora*, which still survive. *Nodelia*, *Multelia*, *Osculipora*, *Truncatula*, *Cellulipora*, and *Semimultisparsa* are peculiar to the Chalk. *Alveolaria*, though characteristic of the Crag, commences in the Chalk. Among Tertiary types which survive are *Cellepora*, *Cumulipora*, and *Eutalopora*. *Buskia* is characteristic of the Oligocene.[1]

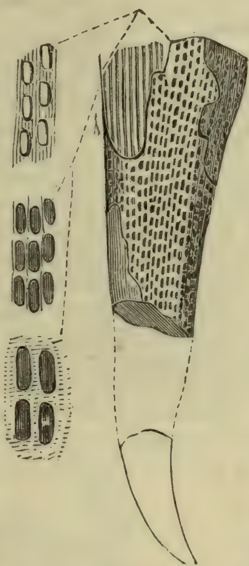


Fig. 116.—Fenestella.

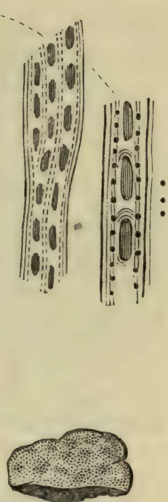


Fig. 117.—Monticulipora.

Brachiopoda.—Brachiopods are symmetrical bivalve shells, which are equal-sided, but usually inequivalve. In most genera the valves are locked together; the larger valve is perforated by a foramen, giving passage to a ligament, by which the shell is attached; and

[1] The Bryozoa of the Crag by Busk has been published by the Palæontographical Society.

several genera are characterised by the internal shelly plates, loops, and spirals (see fig. 118) which support the breathing organs. Most of the genera are extinct and confined to the Primary rocks, though several primary genera range up to the lower Oolites. We first enumerate some of the extinct genera. *Spirifera* and *Atrypa* range through the Primary to the Trias, *Orthis* and *Strophomena* only range up to the Carboniferous, *Obolus* and *Siphonotreta* are Cambrian and Silurian, *Uncites* is Devonian, and *Stringocephalus*, *Merista*, and *Pentamerus* are Silurian and Devonian; *Chonetes* ranges from Cambrian to Permian, and *Producta* and *Strophalosia* from Devonian to Permian. Several genera extend up to the Trias; among them are *Cyrtia*, *Retzia*, which both date from the Silurian; and *Davidsonia*, which dates from the Devonian. Other genera range up to the Lias; among them are *Leptæna* and *Athyris*. *Koninckia* is confined to the Trias; *Suessia* is confined to the Upper Lias. *Spiriferina* extends from the Devonian to the Lower Oolite, *Zellania* extends from the Lias to the Great Oolite. *Kingena*, *Magas*, *Trigonosemus*, and *Lyra* are Cretaceous.

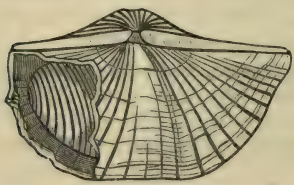


Fig. 118.—Spirifera.

Fig. 119.—Magas.

Of genera which date from the older primary rocks and still survive, the most important are *Lingula*, *Crania*, *Discina*, and *Rhynchonella*. *Terebratula* survives from the Devonian, *Waldheimia* from the Trias. *Thecidium* first appears in the Carboniferous, *Terebratella* in the Lias, *Argiope* in the Inferior Oolite; the living *Terebratulina* is found in the Oxfordian rocks.[1]

Fig. 120.—Rhynchonella.

Fig. 121.—Terebratula.

Fig. 122.—Terebratula.

At the present day Brachiopods live in all depths of water and in all seas.

Lamellibranchiata. — The unsymmetrical bivalve shells vary greatly in form. Occasionally some species of *Pecten* and a few other genera have the right and left sides of the shell equal and similar, and although the right and left valves of the shell are commonly equal, yet in many genera, such as *Ostrea*, *Corbula*, and the common scallop, the valves are unequal. As among the other large groups of

[1] See Davidson, "Fossil Brachiopoda" (Palæontographical Society); and Zittel, "Handbuch d. Palæontologie."

Mollusca, several of the existing genera date back to the Primary period. An attempt is sometimes made to separate the Primary from the Secondary species of the same genus, and although this is often legitimate from the point of view of classification, we prefer in this summary to use generic names in the large synthetic sense of the older naturalists.

The Primary rocks are characterised by the extinct genera of bivalves, *Pterinœa*, *Ambonychia*, *Modiolopsis*, *Lyrodesma*, *Cardiomorpha*, *Cardiola*, *Conocardium*, *Megalodon*, *Anthracosia*, *Eurydesma*, *Pachydomus*, *Poseidonomya*, *Myalina*, *Solemya*. A few genera range into the Secondary Rocks, like *Poseidonomya*, which reaches the Trias. *Pleurophorus* and *Axinus* also reach the Trias.

Ostrea is said to commence in the Carboniferous rocks, but abounds in the Secondary and all newer strata.

Among the genera characteristic of the Secondary rocks are *Inoceramus*, which ranges to the Chalk and may begin in the Silurian; *Aucella*, which begins in the Permian and ranges to the Gault; *Myoconcha* commences in the Permian and ranges up to the Middle Tertiary. *Monotis* and *Myophoria* are Triassic. *Sphæra* ranges from the Trias to the Lower Tertiary. *Opis* is limited to the Secondary Strata, as are *Exogyra*, and *Gryphœa*. *Cardinia*, *Goniomya*, and *Unicardium* extend through the Lias and Oolites. *Tancredia* characterises the Lias and Lower Oolites. *Hippopodium* is Liassic. *Pteroperna*, *Macrodon*, and *Pachyrisma* are distinctive of the Lower Oolites. *Protocardium* ranges from the Lower Oolites to the Chalk; *Ceromya*

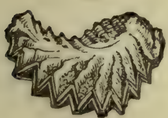


Fig. 123.—Ostrea.

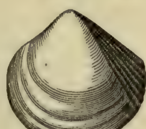


Fig. 124.—Protocardium.

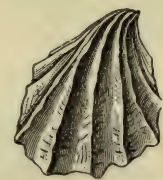


Fig. 125.—Inoceramus.

and *Cercomya* range from the Lower Oolites to the Upper Greensand. *Disceras* and *Isodonta* are distinctive of the Middle Oolites. *Monopleura* and *Requinia* range from the Neocomian to the Upper Greensand. These genera have no recent representatives.

The living genera which may be considered to have representative species that date from the Primary rocks are *Avicula*, *Arca*, *Cypricardia*, *Lucina*, *Cardium*, *Pinna*, *Pecten*; *Mytilus* does not appear till the Permian. With the Trias *Lima*, *Plicatula*, *Perna*, *Nucula*, *Trigonia*, *Cyprina*, *Isocardia*, *Cardita*, and *Corbis* come in. Among genera which appear with the Lias are *Astarte*, *Mactra*, *Pholodomya*, *Teredo*, *Leda*. The Lower Oolites first make us acquainted with *Anomia*, *Lithodomus*, *Limopsis*, *Venus*, *Tellina*, *Corbula*, *Panopea*, *Anatina*, *Thracia*, and *Gastrochœna*. There are no new genera introduced in the Middle or Upper part of the Oolites,

The Wealden beds first being in *Unio*, *Cyclas*, and *Cyrena*. The Neocomian seas introduced *Pectunculus*, *Spondylus*, *Crassatella*, *Thetis*, *Mesodesma*, and *Solecurtus*. The Upper Greensand introduces *Cre-*

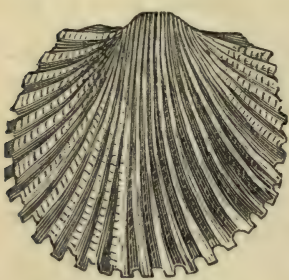


Fig. 126.—Cardium.

Fig. 127.—Trigonia.

nella, *Chama*, *Capsula*, *Machaera*, *Clavagella*. The Chalk makes *Vulsella* known. The following genera come in the Lower Tertiary period—*Nucinella*, *Lithocardium*, *Cryptodon*, *Diplodonta*, *Pythina*, *Petricola*, *Psammobia*, *Sanguinolaria*, *Semele*, *Syndosmya*, *Donax*, *Solen*, *Potamomya*, *Pandora*, *Pholas*, *Teredina*, and *Cardilia*. The Middle Tertiary makes known *Artemis*, *Trigona*, *Lucinopsis*, *Tapes*, *Venerupis*, *Lutraria*, *Gastrana*, *Mya*, *Glycimeris*. *Yoldia*, *Solenella*, *Tridacna*. Very few genera appear in the Upper Tertiary strata which were not previously known. The range in time of genera is always being carried further back, and needs to be considered by the student as affecting the locality or district under consideration; for the object of all collections of fossils is to demonstrate the local geographical distribution of life in geological time. The use of a summary consists in the evidence it furnishes of the change of life in time, by indicating epochs when new genera made their appearance. It is only, however, after comparison of the later forms with the types with which they have family affinities, that we recognise the evolution which they represent.[1]

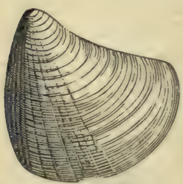


Fig. 128.—Pholadomya.

Gasteropoda.—So far as the palæontologist is concerned, the soft Gasteropoda which have no shells may be disregarded, and we may define the class palæontologically as characterised by having the body more or less perfectly contained in a shell which usually consists of one piece, with the aperture often closed by a horny or shelly operculum. The shell may be tubular, as in *Dentalium*, conical, as in *Patella;* but more commonly exhibits some degree of spiral growth. Comparatively few genera are absolutely extinct. *Murchisonia* is

[1] See "Structural and Systematic Conchology," by George W. Tryon, Philadelphia, 1882. Also Woodward's "Manual of the Mollusca," of which it is a new edition.

characteristic of the Primary rocks, *Loxonema* and *Euomphalus* range through the Primary to the Trias, *Holopea* is Cambrian, *Macrocheilus* is limited to the Devonian and Carboniferous rocks, *Nerinœa* ranges from the Inferior Oolite to the Upper Chalk, *Trochotoma* extends from the Lias to the Coral Rag, *Rimula* extends from the Great Oolite to the Coral Rag.

Fig. 129.—Holopea.

The existing genera which are known to commence in the older Primary rocks are not very numerous; the oldest are *Turbo*, *Chemnitzia*, *Patella*, *Chiton*, and *Pleurotomaria*. With the Devonian rocks *Natica*, *Trochus*, *Dentalium*, and *Phasianella* begin. *Calyptrea* and *Fissurella* may date from the Carboniferous, and *Rissoa* appears with the Permian strata. With the Secondary strata *Emarginula* and *Cerithium* commence in the Trias. The Lias contains the oldest known species of *Pteroceras*, *Aporrhais*, *Nerita*, and *Pileopsis*. *Fusus* is first known from the Bath Oolite, *Scalaria* from the Coral Rag, *Melania*, *Paludina*, and *Valvata* are known first from the Wealden, *Rostellaria*, *Pyrula*, *Turritella*, and *Vermetus* from the Neocomian; while the Chalk brings in *Strombus*, *Fasciolaria*, *Cancellaria*, *Dolium*, *Conus*, *Plurotoma*, *Voluta*, *Mitra*, *Cypræa*, *Phorus*, and *Hipponyx*. In the Lower Tertiary strata fossil species are met with of *Seraphs*, *Murex*, *Typhis*, *Ranella*, *Triton*, *Terebra*, *Nassa*, *Purpura*, *Cassis*, *Cassidaria*, *Oliva*, *Ancillaria*, *Volvaria*, *Ovulum*, *Potamides*, *Melanopsis*, *Solarium*, *Neritina*, *Crepidula*. In the Middle Tertiary the genera *Turbinella*, *Haliotis*, and *Litorina* are found for the first time.[1]

Fig. 130.—Voluta (Lower Tertiary type).

Fig. 131.—Voluta. (Upper Tertiary type).

Cephalopoda.—Cephalopoda include a large number of extinct

[1] Monographs of the British Tertiary Mollusca by Searles Wood have been published by the Palæontographical Society.

genera. The Tetrabranchiata is the older group, comprising the animals which dwell in chambered shells, and have a siphuncle running through the chambers. This group is represented at the present day by the *Nautilus.* The genera are chiefly distinguished from each other by the mode of the growth of the shell, the character of the margin of the septa, and the position of the siphuncle. These differences are all connected with the development of the reproductive organs, and positions of the muscle which holds the animal in the shell. Two principal types are known, represented by the Ammonite, which has the septa folded; and the Nautilus, which has the septa simple. The Nautilus dates from the Cambrian strata, and is met with in all subsequent deposits. It becomes most specialised in the form of the shell in the Carboniferous limestone, and in folding of septa in the Palæozoic genus *Clymenia*, and the Tertiary group *Aturia*, found in the London clay: *Discites* ranges from Cambrian to Carboniferous; *Cryptoceras* is Devonian and Carboniferous; *Temnocheilus* and *Trematodiscus* are both Carboniferous; *Hercoglossa* is Cretaceous and Lower Tertiary; *Cinonia* is confined to the Lower Tertiary. *Lituites* and *Trochoceras* are both lower Palæozoic genera; *Gomphoceras*, *Phragmoceras*, and *Cyrtoceras* are genera ranging from the Cambrian to the Carboniferous; *Orthoceras* ranges from Cambrian to Trias, and includes multitudes of species. *Gyroceras* and *Goniatites* range from the true Silurian to the Trias; *Rhabdoceras* is Triassic; and though *Ceratites* is chiefly known from the Trias, it ranges from the Devonian to the Chalk.

Fig. 132.—Nautilus.

Fig. 133.—Goniatites.

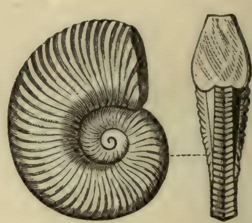


Fig. 134.—Ammonites.

The genus AMMONITES has been divided into sub-genera, distinguished by folding of the septa and form of the shell. Among them are *Sageceras*, which is Permian and Triassic; *Arcestes*, *Didymites*, *Lobites*, *Pinacoceras*, *Ptychites*, *Trachyceras*, and *Tropites*, which are exclusively Triassic; *Ægoceras* is Triassic and Liassic; *Amaltheus*, *Lytoceras*, *Phylloceras* are Triassic, Jurassic, and Cretaceous; *Arietites*, *Harpoceras*, *Ækotraustes*, *Oppelia*, *Peltoceras*, *Stephanoceras*, *Simoceras*, &c., are Jurassic; *Aspidoceras*, *Cosmoceras*, *Haploceras*, and *Perisphinctes* are Jurassic and Cretaceous; and *Acanthoceras*, *Olcostephanus*, *Schlœubachia*, *Stoloczkaia*, &c., are Cretaceous.

The genera which differ from *Ammonites* in their uncoiled mode of

growth of the shell comprise *Ancyloceras* and *Helioceras*, which range from the Inferior Oolite to the Chalk; *Crioceras* and *Toxoceras* extend from Neocomian to Upper Greensand; *Hamites*, *Ptychoceras*, and *Baculites* range from the Neocomian to the Chalk, while *Turrilites* ranges from the Gault to the Chalk, in which it is most developed.

The Tetrabranchiata are therefore of great stratigraphical value; and the large number of fossil species invests them with importance, for it would be easy to make a Table of strata in which each marine bed was distinguished by well-characterised and easily-recognised Cephalopods.

The Dibranchiata are especially characteristic of existing seas; they are naked Cephalopods, which have an internal shell or pen, an inkbag about the mouth, and only eight or ten arms, which are provided with suckers or horny hooks. No representative of the group has been found in the Primary rocks; it begins with the Lias, where the living genus *Loligo* first appears. *Teudopsis*, *Belotheuthis*, *Geötheusis*, and *Plesiotheusis* are all Liassic genera which range into the Lower Oolites. *Leptotheuthis* is found in the Oxford clay and at Solenhofen. *Ommastrephes* ranges from the Oxford clay to existing seas; and *Enoplotheuthis* from the Oolite to existing seas.

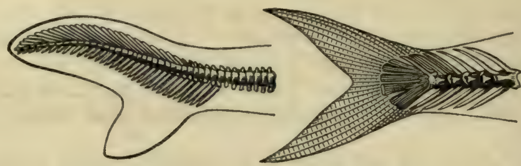
The most interesting genera of Dibranchiates are the *Belemnites*, which are almost entirely Secondary. Belemnites range from the Lias to the Chalk, though a belemnite-like fossil has been found in the Tertiary of South Australia. *Xipoteuthis* is a genus with a fusiform phragmocone found in the Lias. *Belemnoteuthis* characterises the Oxford and Kimmeridge Clays. *Conoteuthis* ranges from the Neocomian to the Upper Greensand. *Belemnitella* is limited to the Upper Greensand and Chalk. *Sepia* has survived from the Oxford clay; and the allied *Belemnosis* and *Beloptera* are found in the London Clay and Bracklesham beds.

Fig. 135.—Belemnitella.

Fishes.—Although existing fishes are divided into four sub-classes, Palæichthyes, Teleostei, Cyclostomata, and Leptocardii, only the two former can be recognised in a fossil state. The Palæichthyes, which comprise the majority of the fishes found in the older rocks, are divided into five orders,—the Dipnoi or mud fishes, the Ganoidei, the Holocephala or Chimæras, the Plagiostomata or sharks and rays, and the Chondrostei or sturgeons. Palæichthyes have a spiral valve to the intestine. Dr. Günther remarks that they stand to the Teleostei in the same relation as the Marsupialia to the Placentalia among mammals. This view is perhaps favoured by Alexander Agassiz's embryological work,[1] which has shown that Teleostean fishes in an early stage of development have the tail symmetrical, without either the homocercal or the heterocercal modification (fig. 136), such as is seen in most of the Ganoids of the Old Red Sandstone and in the

[1] Young, "Stages of some Osseous Fishes," Proc. Americ. Acad., vol. xiii., xiv., xvii.

living *Ceratodus.* The sharks are one of the most ancient groups of fishes; at least one of the oldest known fishes from the Ludlow bone bed, *Onchus,* is a shark. It is succeeded in the Devonian rocks by *Dimeracanthus* and *Homacanthus.* In the Carboniferous rocks succeed *Oracanthus, Gyracanthus, Tristychius, Astroptychius, Ptychacanthus,* and *Sphenacanthus.* In the Coal-measures are found such types as *Cladacanthus, Leptacanthus,* and *Gyropristis. Leptacanthus* ranges from the Coal to the Oolite. The Trias yields some peculiar genera like *Nemacanthus* and *Liacanthus;* while *Asteracanthus, Myriacanthus,* and *Pristacanthus* are known from the Oolites. These are a few of the genera founded upon fish spines. Several existing genera of sharks are actually or closely represented in the strata,—thus *Corax,* closely allied to the Blue Shark, is Cretaceous, and Tertiary. *Carcharias* is found in the Chalk, in which *Hemipristis* and *Galeocerdo* occur. The Lamna family, which comprises the living porbeagles, first appears with *Carcharopsis* in the Carboniferous period. *Carcharodon,* which yields teeth in the Crag five inches long, is not known to attain a greater length than forty feet, though teeth as large as the crag teeth occur at the bottom of the Pacific: it is recorded from the Maestricht beds and ranges through the Tertiary. The genus *Lamna,* which includes *Oxyrhina,* is abundant in the Cretaceous and dates back to the Wealden. Among allied fossil types are *Sphenodus* from the Oolites; *Gomphodus* and *Ancistrodon* from the Chalk. The grey sharks, *Notidanus,* are represented in the Brown Jura, and in this country are found in the Upper Greensand and London Clay. *Ællopos* is found in the Solenhofen Slate. The dog-fishes are well represented in the Secondary strata, and are known as *Scylliodus, Palæoscyllium,* and *Pristiurus,* which is a well-known European genus. The Hybodonts are all extinct. *Cladodus,* in the Devonian and Carboniferous, is the oldest representative of the group. *Hybodus* is said to occur in the Carboniferous and in the Tertiary, but is characteristic of the Secondary Rocks. The Cestraciodonts appear with *Ctenoptychius* in the Devonian, *Psammodus, Cochliodus,* and *Polyrhizodus* in the Carboniferous; *Strophodus* and *Acrodus* in the Oolites; and *Ptychodus* in the Chalk. The picked-dogs are represented in the Lias by *Palæospinax,* but the genus *Spinax* does not date back further than the Secondary Rocks.



Heterocercal. Homocercal.

Fig. 136.—Fish tails.

Orthacanthus of the Carboniferous may have been a monk fish;

the Oolitic *Thaumas* belong to this type. *Squaloraja* of the Lias represents the living *Pristiophorus.* The Rays are represented by the saws of *Pristis* in the London clay and newer rocks. *Spathobatis*

Dorsal spine. Tooth.

Fig. 137.—Hybodus.

is a ray from the Oolites. The torpedoes appear in the genus *Cyclobatis* in the Cretaceous of Lebanon, though the genus *Torpedo* is first found in Monte Bolca. *Arthropterus* from the Lias was a true ray, and ray spines are met with in the Coal and in Crag. The sting-rays are numerous in the Lower Tertiary; the eagle ray *Myliobatis*, with the allied genera *Ætobatis* and *Rhinoptera*, characterise the Lower Tertiary, and *Zygobatis* is found in the Crag. The Chimæras appear in the Devonian, according to Dr. Newberry, with *Rhynchodus. Ganodus* is found in the Lower Oolites. *Ischyodus* ranges from the Lias to the Chalk. *Edaphodon* is Cretaceous, but is represented in the Tertiary. *Elasmodus* and *Psaliodus* are Tertiary. *Callorhynchus*, a living type, is found in the Cretaceous of New Zealand.

The Ganoid fishes have been divided into eight sub-orders. The Placodermi are extinct; they range from the Lower Ludlow to the Carboniferous, but are characteristic of the Old Red Sandstone, and comprise *Pterichthys*, *Coccosteus*, *Dinichthys*, *Cephalaspis*, and the allied forms *Pteraspis*, *Scaphaspis*, *Auchenaspis*, &c. Another sub-order, distinguished by carrying large spines, is represented in the Old Red Sandstone and Carboniferous rocks by *Acanthodes* and *Cheiracanthus.* The Dipnoi are represented by the existing *Ceratodus*, which is found in the Trias and Lower Oolites, but is unknown in newer strata. Closely allied are the extinct *Dipterus* and *Heliopus* of the Devonian; *Phaneropleuron* belongs to the same rocks. The sturgeons are not known prior to the London Clay, though *Polyodon* is represented in the Lias by *Chondrosteus.* The Polypteroid fishes comprise

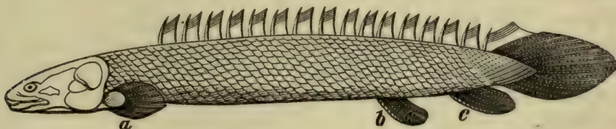


Fig. 138.—Polypterus (living).
a. pectoral fin; *b.* ventral fin; *c.* anal fin.

the *Saurodipterini*, including the Old Red Sandstone *Osteolopis* and *Diplopterus*, and the Carboniferous *Megalichthys.* The Cœlacanthi

include *Cœlacanthus* from the Coal, *Macropoma* from the Kimmeridge Clay and the Chalk, *Rhizodus*, &c. The genera allied to *Holoptychius* include *Glyptolepis*, *Dendrodus*, *Glyptopomus*, *Gyroptichius*, and other

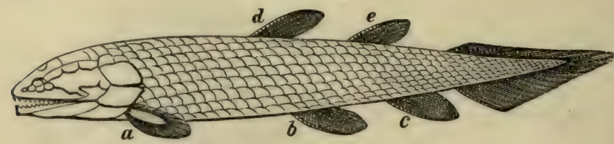


Fig. 139.—Osteolepis restored.
Fins: *a*. pectoral; *b*. ventral; *c*. anal; *d*, *e*. dorsal.

Devonian and Carboniferous genera. The *Pycnodonts* were ganoids; they are represented by *Pleurolepis* and *Homœolepis* from the Lias, and many genera of the Secondary rocks, such as *Gyrodus*, *Microdon*,

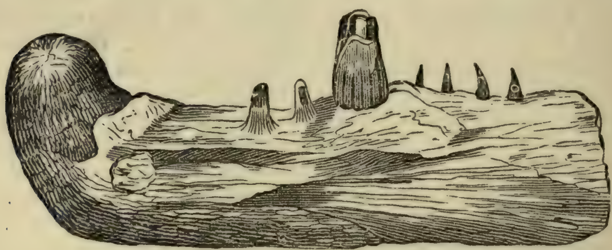


Fig. 140.—Holoptychius (fragment of jaw).

Pycnodus, and *Misodon*, some of which range to the Tertiary. The type represented by the living *Lepidosteus* is a large one. *Lepidosteus* itself is a Lower Tertiary genus. The Sauroid fishes are characteristic of the Lias and Oolites, and comprise such genera as *Semionotus*, *Eugnathus*, *Pholidophorus*, *Pachycormus*, &c., *Tetragonolepis* from the Lias. *Lepidotus* ranges from the Lias to the Chalk. *Aspidorhynchus* characterises the Middle Secondary strata. The allies of *Palæoniscus* range between the Old Red Sandstone and the Lias. *Chierolepis*, *Cosmoptychius*, *Palæoniscus*, *Amblypterus*, and *Pygopterus* are characteristic Primary genera, while the Lias yields other forms like *Centrolepis* and *Cosmolepis*. The allies of *Platysomus* are confined to the Carboniferous and Permian strata. The living American genus *Amia* is the type of the last section of the Ganoids. *Leptolepis* characterises the Lias and Oolites; and *Caturus*, well known from Solenhofen, is found in the Chalk.

The Teleostean fishes are divided into six Orders—the Acanthopterygii, Pharyngognathi, Anacanthini, Physostomi, Lophobranchii, and Plectognathi.

The Acanthopterygii are well represented in a fossil state. The Perch is represented at Oeningen; the Bass, *Labrax*, the genus *Ser-*

ranus, and many other living genera, occur in the Tertiary of Monte Bolca, where the perch of the Nile and Ganges, *Lates*, is also found. The Squamipinnes are also well represented at Monte Bolca, and in the Calcaire Grossier of the Paris basin by *Holacanthus*, *Pomacanthus*, *Ephippium*, *Scalophagus* of the Indian seas, and *Toxotes*. The sea-breams, though found in the Cretaceous of Lebanon in the living genera *Sargus* and *Pagellus*, are known in the older Tertiary from extinct genera, *Sparnodus Sargodon*, &c. The genus *Scorpæna* is found in the Lower Tertiary of Oran, *Beryx* dates back to the Chalk, and many allied genera occur in Cretaceous rocks; while *Holocentrum* and *Myripristis* are allies from the Tertiary of Monte Bolca. Sword-fishes occur in the Chalk, and are represented in the London clay and Lower Tertiary by the extinct genus *Cœlorhynchus*. The Trichiuridæ are represented in the Cretaceous rocks by *Enchodus*, and *Anenchelum* occurs with other typical genera in the Lower Tertiary. The schists of Glarus yield *Palæorhynchus*, and *Hemirhynchus* is found in the Paris basin. *Acanthurus* and *Naseus* are both represented in Monte Bolca. The Horse-Mackerel group is represented in Cretaceous rocks by *Platax*, *Vomer*, &c.; but many other living types occur at Monte Bolca and in newer Tertiary beds. Among extinct genera are *Semiophorus* and *Pseudovomer*. The John Dory, *Zeus*, is found in Tertiary rocks, *Goniognathus* is a fossil of Sheppey, and *Mene* occurs at Monte Bolca.

The Scomberoid fishes are not known prior to the Lower Tertiary, in which the mackerel, *Scomber*, and tunny, *Thynnus*, are common. The Eocene schists of Glarus yield extinct genera, *Isurus* and *Palimphyes*. The Trachinidæ, carnivorous bottom-feeding fish, are represented in the Lower Tertiary rocks by *Callipteryx*. Two or more gurnards, *Trigla*, and fishes closely allied to the Miller's Thumbs, *Cottus*, are found in the Lower Tertiary. The flying gurnard, *Dactylopterus*, is represented in the Chalk of Lebanon by *Petalopteryx*. Gobies first appear in the Chalk; the Blennies are doubtfully represented in the Lower Tertiaries of Monte Bolca, but the Barracudas are represented in the Chalk and London clay by *Hypsodon*, *Portheus*, and *Saurocephalus;* and *Sphyræna* is common in the Lower Tertiary.

The living *Atherina* is represented in the Monte Bolca beds by *Mesagaster;* the grey mullets do not occur prior to the Tertiary period. The great marine Sticklebacks are another group which appear with the Lower Tertiary, *Fistularia* and *Aulostoma* being found at Monte Bolca and Glarus. The remarkable *Amphisile*, sheathed in dorsal armour, is another Monte Bolca fossil.

The Pharyngognathi have the pharyngeal bones in the gullet blended together. They include four families. The Pomacentridæ are represented at Monte Bolca by *Odonteus*, allied to the living Heliastes. The Wrasses are represented by many labroid genera in the Lower Tertiary, such as *Egertonia*, from the London Clay; *Phyllodus* and other types occur in the Miocene, while the genus *Labrus* is found in the Swiss molasse.

The Anacanthini or soft-finned fishes comprise the Cod tribe and the flat fishes. The Ganoid group is not abundant in a fossil state.

The hake *Merluccius*, and fishes allied to the cod, are found in the London Clay. *Palæogadus* and like forms occur in the schists of Glarus. The Pleuronectidæ are carnivorous fishes, dating from the Tertiary period. A species of turbot, *Rhombus*, is found at Monte Bolca, and soles occur near Ulm.

The Physostomi comprises fishes with all the fin rays jointed, though the first rays of the dorsal and pectoral fins are sometimes ossified; it includes thirty-one families. The Siluroid fishes certainly date from the Cretaceous period, though they become characteristic of the Tertiary rocks. The deep-sea Scopelidæ are represented by the so-called *Osmeroides* from Lebanon, and other genera allied to Saurus from Comen in Istria and the Middle Tertiary of Licata in Sicily. The Carps appear in the Middle Tertiary deposits of Œningen and the Lignites of Bonn and Bilin, and are mostly referable to existing genera, *Cyprinus, Tincta, Leuciscus, Rhodeus, Cobitis*. *Cyprinodon* is found at Aix in Provence and the Middle Tertiary of Germany. The Scombresocidæ are represented at Monte Bolca by *Holosteus*, and in some Middle Tertiary beds by the gar pike, *Belone*. The true pike, *Esox*, dates from the Œningen beds. The *Osmeroides* of the Chalk is allied to the smelt, and is associated with *Aulolepis, Tomognathus*, and *Acrognathus*, which probably belong to the salmon family.

The herrings are represented in the Gault by *Thrissopater;* in the Chalk by *Opisthopteryx*, while *Clupea, Engraulis* the anchovy, and *Chanos* of the Indian seas are found in the Lower Tertiary associated with many extinct genera. The Hoplopleuridæ is an extinct family, first known in the Chalk, and extending into the Tertiary, represented by *Saurorhamphus, Pelargorhynchus*, &c. Finally, the Eels are represented in the London Clay by *Rhynchorhinus*, and in the Monte Balca beds occur the living *Anguilla*, and the tropical *Ophichthys*.

The Lophobranchiate order is represented by the Tertiary genus *Solenorhynchus*, the true pipe fish *Syngnathus*, and the sea-horse *Calamastoma*, found at Monte Bolca.

The order Plectognathi comprises fishes with rough scales, or spiny ossifications in the skin, and few imperfectly ossified vertebræ. The Scleroderm family is represented by *Glyptocephalus* of Sheppey, which resembles the living file-fish, *Balistes;* the box-fish, *Ostracion*, occurs at Monte Bolca; and the schists of Glarus yield *Acanthoderma* and *Acanthopleurus*. The Gymnodonts are represented in a fossil state by a *Diodon* at Monte Bolca, *Enneodon* from Monte Postale, and *Trigonodon* from the Middle Tertiary of Turin.[1]

If the Lampreys occur in a fossil state, they are only known from their dental plates. Organs which closely resemble the teeth of living Cyclostomata are frequently met with in the Cambrian, Silurian, and Devonian rocks, and are known as *Conodonts*.

Amphibia.—The amphibia are a group which exemplify the evolution of animals in the circumstance that they begin life as fishes,

[1] See Pictet: "Traité de Paléontologie," Tom. II., Günther's "Study of Fishes," and monographs by E. Ray Lankester, and by Traquair, in Palæontographical Society's Publications.

pass through a metamorphosis, and become air-breathers. The chief characters are the two occipital condyles to the skull, the absence of sternal ribs, and the naked skin. The group as known at the present day includes three sections—first Saurobactrachia or Urodela, which comprises the Proteidea and Salamandridea; secondly, the Gymnophiona, which includes the Cæciliidæ; and thirdly, the Anura, which comprises frogs, toads, and their allies. The extinct Labyrinthodontia have the external skeleton much developed, especially on the ventral side of the body. Professor Cope has united the Labyrinthodontia with the Ganocephala and Microsauria in one group, which he names Stegocephali. With one or two exceptions the fossil types belong to this group, and are found between the Carboniferous rocks and the Trias. Among the Carboniferous genera [1] in Europe are *Anthracosaurus*, *Loxoma*, *Bratrachiderpeton*, *Pteroplax*, *Pholidogaster*, *Ichthyerpeton*, *Pholiderpeton*, *Lepterpeton*, *Urocordylus*, *Erpetocephalus*, *Keraterpeton*, *Megalerpeton*, *Ophiderpeton*, *Dolicosoma*; *Protriton* and *Pleuronura* are found in France. *Archægosaurus* is common in Germany. In North America these organisms are as well developed. In Nova Scotia *Dendrerpeton*, *Hylonomus*, *Hylerpeton*, *Baphetes*, and *Eosaurus* occur, and in the coal-field of Ohio *Amphibamus*, *Brachydectes*, *Eupelor*, *Eurythorax*, &c. Several of these types range to the Permian, from which Fritsch [2] has described a large fauna in Bohemia. It includes the genera *Branchiosaurus*, *Sparodus*, *Hylonomus*, *Dawsonia*, *Melanerpeton*, *Dolichosoma*, *Ophiderpeton*, *Palæosiren*, *Adenoderma*, *Urocordylus*, *Keraterpeton*, *Limnerpeton*, *Hyloplesion*, *Seeleya*, *Ricnodon*, *Orthocosta*, *Microbrachis*, &c.

Fig. 141.—Branchiosaurus salamandroides (Fritsch),[3] twice the natural size.

Dr. Fritsch describes *Branchiosaurus* as resembling the Earth-

[1] See C. L. Miall: Rep. Brit. Assoc. 1873, 1874.

[2] "Fauna der Gaskohle, und der Kalksteine, der Permformation Böhmens." Prague.

[3] From Fritsch's "Fauna der Gaskohle," &c. Prag. 1879. Electrotypes of the specimens figured have been published.

salamanders, especially the young forms, in possessing gills; and in the broad head rounded in front, the short thick well-developed extremities terminating in digits, and in the rudder-like tail which strongly suggests the larval forms of living Urodela. The skin was dense, and its impression is preserved and shown in the figure. The form of the skull will be gathered from the figure, 142, in which Professor Fritsch has restored the upper surface of the skull of *Branchiosaurus*, enlarged six times. The lettering indicates the same

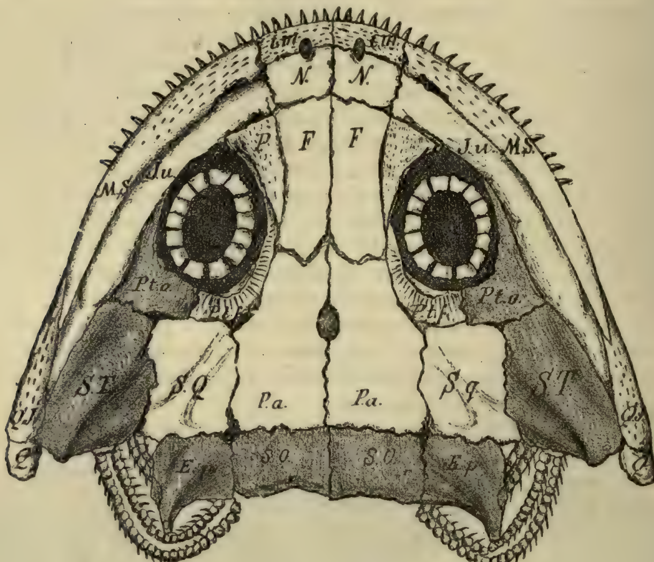


Fig. 142.

bones as in the skull of *Dolichosoma*. There are about 20 vertebræ in the neck and back, and 21 in the tail.

Dolichosoma longissimus (Fritsch) may serve as another type of amphibian structure. It is described by Professor Fritsch as distinguished by having the ribs twice as long as the vertebræ. In form it closely resembles the whip-snake (*Dendrophis*). The fragment found measures 60 cm., and indicates for the entire animal a length of about a mètre. An impression of the skin is preserved; enlarged 45 times it shows a fine granular structure, so that if any scales existed they are not preserved.

The eyes are placed rather behind the middle line of the skull, and are separated by an interspace of two-thirds their diameter. The parietal foramen (*Pa*) lies far behind the orbits. The anterior nares cannot be distinguished. The nasal bones (*N*) are anchylosed toge-

ther, and forked behind. The premaxillaries (*im*) resemble those of *Siren lacertina.* The maxillary (*ms*) is a strong bone extending to the anterior extremity of the snout, and to the middle of the orbit;

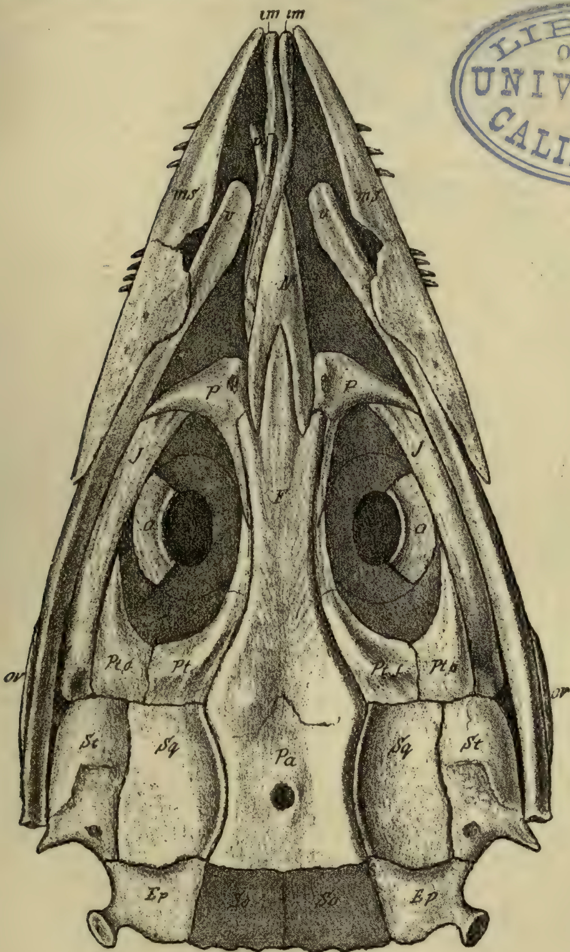


Fig. 143.
Dolichosoma longissimum, upper surface of skull restored, enlarged six times.

it carries about 15 smooth teeth, which are curved backward: there may have been two rows. The frontal (*F*) and parietal (*Pa*) bones are blended into one mass. The frontal terminates in front in three processes. The epiotic bone (*Ep*) terminates at its outer angle in a knob-like swelling. The teeth of the lower jaw, 20 in number, were

smaller than those in the upper jaw. There are indications of a branchial skeleton extending to the sixteenth vertebra. One hundred and fifty vertebræ are preserved, but there may well have been fifty more. In the neck the ribs are simple, in the body they are complicated, and in the tail they are absent. The dorsal vertebræ have a depressed elongated quadrate form, with a ridge in the position of the neural spine; the neural arch is constricted in the middle, and terminates at its four corners in zygapophyses. The transverse processes are compressed, directed downward and outward, and given off

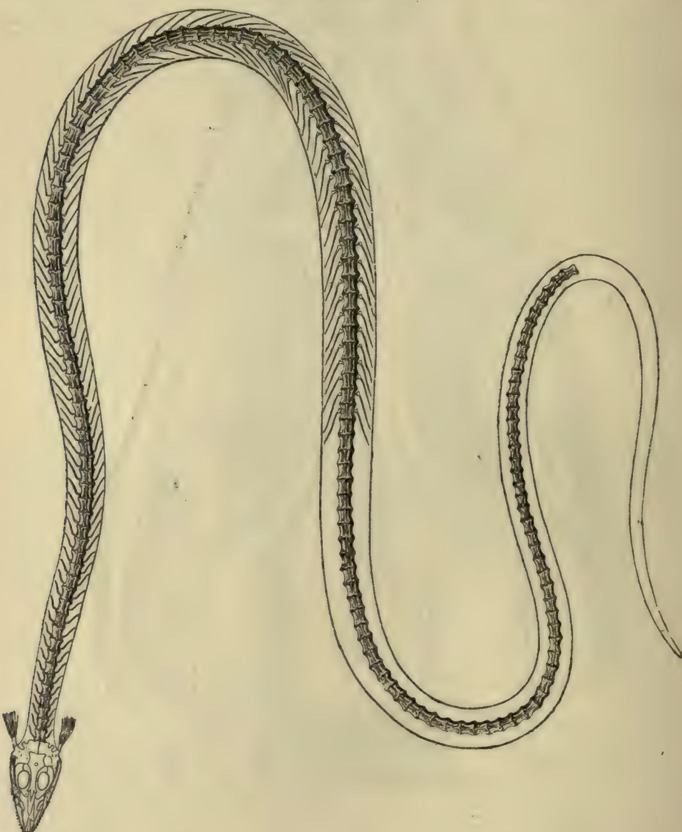


Fig. 144.
Dolichosoma longissimum (Fr.), restoration half natural size. From the Coal of Nyran.

from the lower margin of the front of the centrum. The centrum has a circular cup at each end, and the cones unite, so that the notochord was persistent. The form of this vertebra may be compared

with that of *Epicrium glutinosum.* Each vertebra has a slightly different shape. The tail vertebræ are smaller and shorter, and have weak zygapophyses, and are perforated in the middle of the side as though for the passage of an intervertebral nerve. The ribs of the neck at the sixteenth vertebra are twice as long as the centrum. The dorsal ribs show towards the proximal end two peculiar processes. The proximal end is bent at nearly a right angle to the body of the rib; the processes occur at the flexure, one is dorsal, and the other has a ventral direction. These processes present some analogy to the uncinate processes on the ribs of birds.

Other Permian types in this country are *Dasyceps* and *Lepidotosaurus.* In Russia, *Zygosaurus* and *Melosaurus.* The Trias yields *Mastodonsaurus*, *Capitosaurus*, *Trematosaurus*, *Metopias*, *Labyrinthodon*, *Diadetognathus;* from Australia, *Bothriceps;* from South Africa, *Micropholis;* from India, *Gonioglyptus* and *Pachygonia;* and *Brachyops*, which is said to be Jurassic.

The modern batrachians are only found in the Tertiary strata. They include species of *Rana*, *Palæobatrachus*, *Asphærion*, *Latonia*, *Pelophilus*, *Pelæophrynos*, and the Urodelians are the great *Andreas*, *Triton* and *Orthophya.* Fossil amphibians of the Trias, like Mastodonsaurus, attain to a larger size than living types, and the ancient amphibia are in no sense the ancestors of the living amphibia; so there is no evidence of evolution of existing reptilia from fossil reptilia, because the surviving reptiles are less specialised or degraded forms. Types become degraded because higher organisms in the existing condition of nature restrict the conditions of their activity, in much the same way that the higher branches of the human race affect aboriginal races.

Fossil Reptiles.—The Secondary Rocks have often been termed the Age of Reptiles.

The reptilia are divided into two sections; first, *Cainosauria*, which comprises the Lacertilia and Ophidia; and, secondly, *Palæosauria*, which includes Rhynchocephalia, Chelonia, Crocodilia, Plesiosauria, Anomodontia, Ichthyosauria, and Dinosauria. The Cainosauria attain their maximum development in the existing life of the world, but all the groups of the Palæosauria (except, perhaps, the Chelonia) have their chief development in the Secondary rocks.

CAINOSAURIA.—*Ophidia.*—Very little is known of serpents in a fossil state. The oldest serpent yet known is the sea-serpent of the London Clay and Bracklesham beds, *Palæophis*, which reached a length of from twelve to twenty feet. From Hordwell the genus *Paleryx* is obtained, which closely resembles *Eryx.* A poisonous serpent has been described from Salonica under the name *Laophis. Coluber* is known from the schists of Æningen.

Pythonomorpha.—Under this name Professor Cope indicated *Mosasaurus* and its allies. Professor Owen regards these animals as a family of the Lacertilia. The Lacertilia might certainly be subdivided into several sub-orders, and there can be no reason for hesitating to admit *Mosasaurus* to at least the same rank. The name *Pythonomorpha* is

taken merely to indicate the elongated form of these marine animals, which had the anterior limbs expanded into fins like those of Chelonians or Cetaceans. *Mosasaurus* in this country is found in the

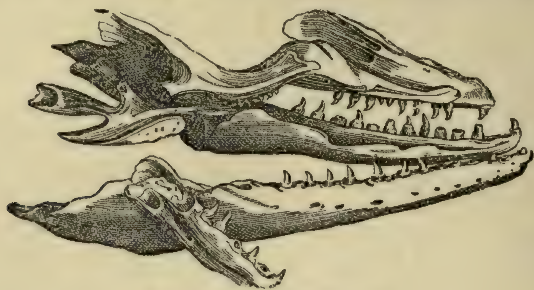


Fig. 145.—Head of Mosasaurus.

Upper Chalk; it is best known from the Maestricht beds. The genera recognised in the Niobrara group of North America are *Platycarpus*, *Clidastes*, *Leiodon*, *Sironectes*.

The Dolichosauria is another well marked sub-order distinguished by having many vertebræ in the neck; the intervertebral articulation includes a zygosphene; the limbs are small. The genera *Dolichosaurus* and *Saurospondylus* are both from the Chalk.

The Homœosauria [1] is a group of Lizards with biconcave vertebræ which ranges from the Trias to the Solenhofen Slates, and includes *Telerpeton* [2] in the former, and *Saphæosaurus* and *Homœosaurus* [3] in the latter.

Lacertilia.—The typical Lizards are represented in the Tertiary strata of Europe by *Iguana* and *Lacerta;* and some fragments have been referred to *Scincus* and to *Anguis.*

PALÆOSAURIA.—*Rhynchocephalia.*—This group, now almost extinct, has for its sole surviving representative the Hatteria of New Zealand. This animal is often classed with the lizards, which it resembles in form and size. It, however, has so many characters in common with the older crocodilia and their allies, that it is conveniently grouped with the Palæosauria rather than with the Cainosauria. *Procolophon*, and many similar animals from Cape Colony regarded as Triassic, may be placed in this group. Professor Huxley would place here the British Triassic *Hyperodapeton* and *Rhynchosaurus.* Professor Cope has referred many American genera to this type.

Chelonia.—Chelonians, so far as is known, retain the carapace and plastron, more or less developed in all fossil forms. The Chelonia have been divided into three principal groups—first, Dematochelyidæ, in which the carapace is not developed, but represented by a tesselated bony skeleton within the skin, such as is seen in the

[1] Huxley: "Anatomy of Vertebrates," 1871.
[2] Huxley: Q. J. G. S., vol. xxiii.
[3] Von Meyer: "Fauna der Vorwelt."

leathery turtle *Sphargis* and the fossil *Psephophorus;* second, the Peltochelyidæ, including the Trionychidæ, in which there are no horny scutes, but a granular bony skeleton, like that of the Dermatochelyidæ, is superimposed upon the bony skeleton of the carapace and plastron; third, the Aspedochelyidæ, which comprises turtles, emydians, and tortoises, distinguished by symmetrical horny scutes covering the bony carapace.

We might expect the simple shield of *Sphargis* to be the oldest, then theoretically it should precede *Trionyx;* but *Sphargis* is only known from the Upper Tertiary, and Trionyx dates back to the Cretaceous of the United States. The majority of Chelonian fossils belong to the Emydian type. Among tortoises may be mentioned the gigantic *Colossochelys*, of the Siwalik beds, and many species of Testudo. Professor Cope records *Protostega*, the type of a family in which the large dermal bones are separate from the ribs. *Toxochelys* belongs to the marine chelonia. In Europe, true marine chelonians are best known from the Chalk and London Clay in this country, though they are said to date back to the Purbeck. The Emydians comprise, among other types, *Pelobatochelys* and *Enaliochelys* from the Kimmeridge Clay, which also yields *Plesiochelys*, and, according to Sauvage, *Platemys.* The Upper Jurassic rocks also yield *Thalassemys*, *Tropidemys*, *Craspedochelys*, which have not been recognised in this country. *Eurysternon* is characteristic of the Solenhofen slate, *Tretosternon* and *Pleurosternon* characterise the Purbeck and Wealden beds, *Chitracephalus* is found in the Wealden of Belgium, which also yields *Peltochelys*. *Protemys* is found in the Lower Greensand. *Rhinochelys* and *Trachydermochelys* characterise the Cambridge Greensand. In the Tertiary rocks of the Continent are found *Chelydra*, *Trachaspis*, *Apholidemys*, *Palæochelys*. There are many forms referred to Emys, such as most of those which occur in the London Clay [1] and the Middle Tertiary of the Continent.

Crocodilia.[2]—The antecedent group from which a type has been modified is often to be detected in the vertebral characters of the tail. Thus in birds the caudal vertebræ are often bi-concave, and a similar character is found in the tails of crocodiles. Hence, just as birds have existed with bi-concave vertebræ, so also have crocodiles. The Crocodilia are hence often divided into two groups, viz., the Teleosauria, comprising the genera of the older Secondary rocks with flat or concave intervertebral articulation, and the Eucrocodilia, comprising the Cretaceous, Tertiary, and existing procœlous types.

The teleosaurs [3] were preceded by *Belodon* or *Phytosaurus* of the Trias. *Teleosaurus* has a form of head like the gavial of the Ganges; but the posterior nares do not extend so far back. The genus has been divided into several sub-genera. *Mystriosaurus* hast he skull flat and the eyes directed upward; it is found in the Lias. *Macrospondylus* only differs from *Mystriosurus* in the greater length of the ver-

[1] Palæont. Soc.

[2] See W. K. Parker, F.R.S.: Trans. Zoological Soc., vol. xi., part 9, "On Structure and Development of the Skull in Crocodilia."

[3] E. E. Deslongschamps: "Notes Palæontologiques," 1863–1869.

tebræ and the proportions of the limbs, which the palæontologist does not regard as generic characters. *Pelagosaurus* is distinguished by the interspace between the eyes being greater than the diameter of the eye; it is characteristic of the Lias. The name *Teleosaurus* has been reserved for the crocodiles of the Inferior and Bath Oolite, which have large and approximating orbits. The Teleosaurs of the Kimmeridge Clay have the eyes lateral, and have been referred to the genus *Steneosaurus*. *Gnathosaurus* of the lithographic slate is a crocodile with lateral eyes, of doubtful affinity. In the Purbeck and Wealdon beds some crocodiles occur which in cranial characters make a transition towards the modern type. They comprise *Goniopholis*, *Petrosuchus*, and *Theriosuchus*.

The *Eucrocodilia* or *Procœlia* appear for the first time in the Cambridge Greensand, Gosau beds, and Greensand of New Jersey. They are met with in the London Clay and Lower and Middle Tertiaries of Europe. The gavial is found in the Bracklesham beds, and the alligator in the Headon beds.

Plesiosauria.—The Plesiosauria comprise a variety of saurians. They include two principal groups—the Nothosauria of the Trias and the Plesiosauria which range from the Rhætic beds to the Chalk. These groups are linked together by the triassic genus *Neusticosaurus*, which exhibits a land animal in process of acquiring the aquatic limbs of the plesiosaur.[1] At first sight, plesiosaurs offer many characters in common with chelonians, such as the forms of the pelvic bones and pectoral bones, and even in the shape of the larger-limb bones, especially as seen in the Nothosauria. But as the anatomy is examined in detail, there are many suggestions of affinity to crocodiles. All plesiosaurs have the palate closed, and the teeth in distinct sockets, the eyes midway in the side of the head, usually a long neck, the cervical ribs occasionally have the articulation double, frequently single. *Elasmosaurus* has no interclavicle. The terrestrial plesiosaurs become greatly modified, and apparently develop into the Anomodontia. The British fossil genera are at present only defined in a few instances; they include the large-headed form with triangular teeth and short cervical vertebræ named *Pliosaurus*, ranging from the Kimmeridge Clay to the Neocomian beds. In the Oxford Clay there is a long-necked type called *Murænosaurus*, with an imperfectly developed pectoral arch, and in the Kimmeridge Clay another Elasmosaurian type named *Colymbosaurus*. There is a stiff-backed plesiosaur called *Stereosaurus* in the Cambridge Greensand, and *Polyptychodon* is a genus of the Greensand and Chalk. All these genera are remarkable for the uniform character of the vertebræ, which are moderately cupped (except in Stereosaurus, where they are flat), and in the dorsal region have the ribs supported upon the neural arch.[2]

Anomodontia.—The Anomodontia have the palate more open

[1] See Monographs on Sauropterygia and Ichthyopterygia by R. Owen, F.R.S., published by Palæontographical Society.

[2] Dr. Lütken regards *Lariosaurus* as a Plesiosaur. See his valuable "Skildringer af Dyrelivet i Fortid og Nutid." Kjobenhavn. 1880.

than in Plesiosaurus. They are divided into three sub-orders, viz., the Dicynodontia, distinguished by two tusks in the position of canine teeth; the Cynodontia, which have teeth anterior and posterior to the canines on the mammalian plan, so that Sir Richard Owen has termed them "Theriodonts;" and, thirdly, the Cryptodontia, in which the jaws are edentulous, and teeth, when present, are palatal. This group is chiefly known from South African fossils. *Rhynchosaurus* and *Hyperodapedon* from the British Trias have been referred by Sir R. Owen to the Cryptodontia. Placodus may be placed here. Many of these Anomodont fossils present so remarkable a resemblance to the lowest types of mammalia in various parts of the skeleton, that the reptiles seem to foreshadow the higher group.[1]

Ichthyosauria.—The Ichthyosauria have a type of skull which differs from that of Dinosaurs chiefly in the enormous prenarial elongation of the snout, and the less perfect ossification of the skull. The squamose overlapping of the bones is also seen in fishes and Cetaceans, and is connected with aquatic habit. The biconcave condition of the vertebral column is closely paralleled in some Dinosaurs from South Africa. The double-headed articulation for the rib is a character only found in association with well-developed ribs in crocodiles and higher vertebrata. The circumstance that the articulation for the ribs descends in position from the neck to the pelvis is associated with marine habit, and the absence of organs ministering to locomotion on land. The scapular arch is in many respects Dinosaurian; the pelvic arch is so feebly developed as only to suggest a generalised reptilian type. Many species of Ichthyosaurus were viviparous.[2] Few genera have at present been defined. A genus of the Oxford clay has been termed *Ophthalmosaurus*, in which there are three bones in the forearm, and the clavicle and interclavicle are united by suture into one mass. A femur from the Cambridge Greensand has been referred to a genus *Cetarthrosaurus*, and is regarded as Ichthyosaurian. Professor Marsh has described an American toothless ichthyosaurus named Sauranodon, which, in other respects, closely resembles the European type. There is no evolution of the Ichthyosaurs at present known comparable to that of Dinosaurs. The oldest species are found in the Rhætic beds, the newest in the Chalk. The remains found in the London Clay are probably derived fossils.

Dinosauria.—The whole of the Dinosauria, so far as is at present known, were land animals, and their remains are most abundant in those formations which give evidence of near proximity to land, such as Trias, Wealden, and Greensand, though they are represented in almost all Secondary deposits. It is probable that *Protorosaurus*, found in the Permian, and best known as the fossil monitor of Thuringia, must be included in the Dinosaurian order. The Trias has yielded (especially from the Bristol conglomerate) remains of *Thecodontosaurus*, *Palæosaurus*, and *Teratosaurus;* but the finest materials of this age are found in Würtemberg, and belong to the genus

[1] See Catalogue of the South African Reptilia in the British Museum. By R. Owen, F.R.S. [2] Rept. Brit. Assoc., Swansea, 1880.

Zanclodon, distinguished by having only two vertebræ in the sacrum. The Lias has yielded the well-armoured genus *Scelidosaurus*, and some undescribed forms. *Megalosaurus*, though best known from the Stonesfield slate and Wealden beds, appears from teeth to date back to the Lias, and survive to the Gosau beds, which are of the age of the Upper Greensand. *Cetiosaurus* abounds in the Forest Marble, Kimmeridge Clay, and Wealden beds. *Cryptosaurus* is found with *Megalosaurus* in the Oxford Clay. *Priodontognathus* probably belongs to the Calcareous grit. Kimmeridge Clay genera include *Omosaurus* and *Gigantosaurus*. The Wealden beds are characterised by *Iguanodon*,[1] perfectly preserved in Belgium, which ranges down to the Kimmeridge Clay, and perhaps upward to the Upper Greensand. With it occur *Hylæosaurus*, *Hypsilosphodon*,[2] *Pelorosaurus*, *Vectisaurus*, *Polacanthus*, and *Ornithopsis*. *Craterosaurus* is found in the Neocomian Sands. The Upper Greensand of Cambridge includes such genera as *Acanthopolis*, *Macrurosaurus*, *Anoplosaurus*, *Syngonosaurus*, and *Eucercosaurus*.[3] The Gosau fauna includes[4] the genera *Mochlodon* *Struthiosaurus*, *Cratæomus*, *Ornithomerus*, *Doratodon* *Rhadinosaurus*, *Oligosaurus*, and *Hoplosaurus*. *Pleuropeltus* may possibly prove to be another Dinosaur allied to *Polacanthus*. The most recent dinosaurs found in Europe are from the Maestricht beds. They are referred to the genera *Orthomerus* and *Megalosaurus*.

The American Dinosauria are numerous. Their exact age is uncertain. Some are Cretaceous; others are regarded as Jurassic. Professor Marsh has greatly subdivided the group,[5] as in the following provisional classification:—[6]

SUB-CLASS—DINOSAURIA.

I. Order—SAUROPODA.

Family Atlantosauridæ: *Atlantosaurus*, *Apatosaurus*, *Brontosaurus*, *Camarasaurus*, *Dystrophæus*.

Family Diplodocidæ: *Diplodocus*.

Family Morosauridæ: *Morosaurus*, *Cetiosaurus*, *Ornithopsis*, *Eucamerotus*.

II. Order—STEGOSAURIA.

Family Stegosauridæ: *Stegosaurus*, *Diracodon* *Omosaurus*.

Family Scelidosauridæ: *Scelidosaurus*, *Acanthopholis*, *Cratæomus*, *Hylæosaurus*, *Polacanthus*.

III. Order—ORNITHOPODA.

Family Camptonotidæ:—*Camptonotus*, *Laosaurus*, *Nanosaurus*, *Hypsilophodon*.

[1] Dollo, Bulletin du Musée Royal d'Histoire Nat. de Belgique.

[2] Hulke, Phil. Trans. Royal Soc., Part III., 1882; *loc. cit.*, Part III., 1881; and numerous papers in Q. J. G. S.

[3] Q. J. G. Soc., vol. xxxv. [4] Quart. Jour. Geol. Soc., vol. xxxvii.

[5] See Marsh, in American Journal of Science, vols. xiv.–xxvii. Cope, United States Geol. Survey of the Territories. vol. ii. 1875, &c.

[6] American Journal of Science, vol. xxiii., January 1882.

Family Ignanodontidæ : *Iguanodon*, *Pelorosaurus*, *Vectisaurus*.
Family Hadrosauridæ : *Hadrosaurus*, *Agathaumus*, *Cionodon*, *Diclonius*.

IV. Order—Theropoda.

Family Megalosauridæ : *Megalosaurus*, *Allosaurus*, *Cœlosaurus*, *Creosaurus*, *Lœlaps*.
Family Zanclodontidæ : *Zanclodon*, *Teratosaurus*.
Family Amhisauridæ : *Amphisaurus*, *Bathygnathus*, *Clepsysaurus*, *Palæosaurus*, *Thecodontosaurus*.
Family Labrosauridæ : *Labrosaurus*.

V. Sub-Order—Cæluria.

Family Cæluridæ : *Celurus*.

VI. Sub-Order—Compsognatha.

Family Compsognathidæ : *Compsognathus*.

VII. Order—Hallopoda.

Family Hallopodidæ : *Hallopus*.

Dinosaurs are to be regarded as modified Crocodiles. The living Crocodilia and the Dinosauria both probably are descended from the Teleosauria. The Teleosaurs which have the articular surfaces of the vertebræ flat or slightly concave, make a slight approximation to Dinosaurs in other parts of the skeleton, and from this Teleosaurian basis all the Dinosaurs may have been evolved by differences of function developed in the several parts of the body. Some of the genera are probably naked, others, like *Polacanthus*, were (as the Rev. Darwin Fox, its discoverer, first pointed out) sheathed in armour only comparable to the carapace of a tortoise or armadillo, Some genera, like *Iguanodon*, had the tail enormously developed; while in others, like some Dinosaurs from the Cambridge Greensand, the tail was almost wanting. Some genera were of the ordinary quadruped type, others had a kangaroo-like form and motion. But the most singular structural modification is seen in *Ornithopsis* and allied genera, in which the vertebræ are excavated by pneumatic cavities comparable to those similarly placed in birds. We should class the Ichthyosauria as an aquatic order in the sub-class Dinosauria, and somewhat simplify Prof. Marsh's classification.

Ornithosauria.—The secondary strata yield between the Lias and the Chalk a remarkable group of flying animals which combined characters of reptiles with those of birds. They were devoid of feathers, and no covering to the skin of any kind has been found. They mostly possessed teeth, better developed than those of the birds from the Secondary rocks ; though *Ornithostoma* from the Cambridge Greensand, and some American types, like *Pteranodon*, were toothless, like existing birds. Perhaps if the toothless forms had been found first, the avian nature of these animals would never have been doubted. The tail was often long; the vertebræ usually, if

not always, have the cup in front and ball behind, as in living crocodiles and most lizards and all serpents, but all the other bones are bird-like in their plan. The wing is only comparable with the wing of a bird, though a digit was elongated to stretch the wing membrane to the same area as feathers extend the wing of the bird. Ornithosaurs could walk on two feet or four feet, but most were aquatic animals, probably divers, living on fish. Air-chambers prolong the breathing organs into the limb bones, as in living birds. The English genera are *Dimorphodon* in the Lias, *Rhamphorhynchus* and *Dolicorhamphus* in the Stonesfield slate; some Pterodactyles occur in the Kimmeridge clay. *Doratorhynchus* is a genus of the Purbeck beds, and *Ornithocheirus*, distinguished by having prehensile teeth directed forward from the front of the snout, ranges from the Wealden beds to the Chalks, and is especially numerous in the Cambridge Greensand. *Ornithocheirus* probably had but three digits in the fore-limb.[1] The Ornithosaurs include the Pterodactylia and Pterosauria.

Aves.—Birds have been divided into three groups: Saururiæ, in-

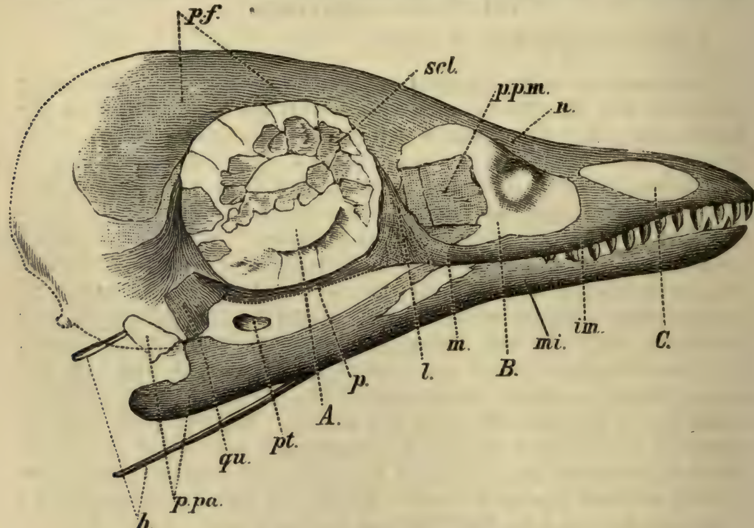


Fig. 146.—Head of Archæopteryx.

A. orbit; *B*. ant-orbital vacuity; *C*. external nasal aperture; *scl*. sclerotic circle; *p.f.* frontal bones; *n*. nasal bones; *im*. premaxillary; *l*. lachrymal; *m*. maxillary; *p.p.m*. palatine plate of the maxillary; *p*. palatine bone; *pt*. pterygoid bone; *qu*. quadrate bone; *mi*. lower jaw; *p.pa*. post articular process of the mandible; *h*. hyoid bones.[2]

dicated by the Archæopteryx; the Ratitæ, including all Struthious birds; and Carinatæ, which comprise birds of flight.

The Archæopteryx is remarkable for having the skull formed upon

[1] See Ornithosauria. 8vo, 1870. Jour. Linn. Soc. Zool., vol. xiii. Annals Nat. Hist., Jan. 1871.

[2] See W. Dames: "Ueber Archæopteryx, Palæontologische Abhandlungen, Zweiter Band," Heft 3, Berlin, 1884, for an admirable discussion of this fossil, and an excellent figure. See also R. Owen: Phil. Trans. Royal Soc. 1863.

the bird plan, with teeth in the premaxillary and maxillary bones. The teeth were in distinct sockets, and appear to have resembled in plan the teeth of Mosasaurus. The tail is elongated as in some ornithosaurs, and the character from being previously unknown among birds has an ordinal value; it suggests the name Saururiæ. The digits of the fore limb are distinct from each other; they are three in number, and each terminates in a claw. These characters are differences from existing birds, but although often taken to indicate a resemblance to ornithosaurs, there is nothing reptilian in the skeleton of the Archæopteryx, except that it is less specialised than the skeleton in existing groups of birds. Feathers in all respects similar to the feathers of existing birds were developed. We are indebted to Professor Dames for the figure of the head. The only specimens known are in the Royal Museum at Berlin, and the British Museum; they are from the Solenhofen Slate.

An American Jurassic bird has been described by Marsh under the name Laopteryx. It is rather larger than a blue heron, but only an imperfectly-preserved skull is described.

Cretacaous birds were first discovered in the Upper Greensand of Cambridge. They are known from fragments, which however proved that some of the vertebræ are bi-concave in the back, that the avian form of articulation exists in the neck, that the head resembles the divers, that the tibia is like that of the grebes, while the pelvis has some characters in common with the penguins. These birds have been referred to the genus *Enaliornis;* but a larger bird existed with them, in which the extremities of the long bones were not ossified. In America Professor Marsh has described, under the name Odontornithes, two genera of toothed birds. One of large size named *Hesperornis* had a very reptilian type of brain. Its teeth are like the teeth of *Archæopteryx;* the sternum has no keel; its scapular arch is small, and the fore limb is represented by a rudimentary humerus. The pelvic arch is not struthious; it is only anchylosed to the sacrum in the acetabular region. The acetabulum is closed by bone. The nearest approach to the legs and feet of *Hesperornis* is seen in the genus *Podiceps.* The bird is regarded as having been aquatic, incapable of flight, with habits comparable to those of the loon. The animal is classed as a carnivorous swimming ostrich. We should rather say a carnivorous natatorial bird, which had not evolved or lost carinate characters. The resemblances of classificational value are all with the water-birds. The resemblances to the ostrich show the direction of the parent stock from which water-birds became evolved.

Ichthyornis is so named because the articular ends of the vertebræ are bi-concave as in fishes. The bird had the wings well developed. Professor Marsh remarks that it can be interpreted by supposing that certain parts have become highly specialised in the direction of the evolution of recent birds, while others have been derived with but little change from reptilian, or even a more lowly ancestry. We should have preferred to say that all the structures which functional conditions have made distinctive of birds are well marked, while some other characters, like

the intervertebral articulation, which varies in the caudal region of existing birds, remain embryonic. We should explain in the same way the ligamentous union of the jaws; and regard the presence of teeth as an embryonic character lost in living birds, much as teeth are lost in the adult whalebone whales. Hence we refer Ichthyornis to the natatorial group of birds. Professor Marsh has described many other cretaceous birds under the names *Apatornis*, *Baptornis*, *Graculavus*, *Laornis*, *Palæotringa*, and *Telmatornis*.[1]

The fossil birds of the Tertiary rocks of Europe have been described in detail by Professor Alphonse Milne-Edwards,[2] but the most remarkable of these remains occur in the Lower Tertiary beds of the Paris basin, from which they have been described by Professor Victor Lemoine, who figures *Gastornis*, *Eupterornis*, and *Renicornis*. Gastornis was a struthious bird, which may have stood 7 or 8 feet high.

Struthious birds found in our own Tertiary strata are represented in the London Clay by *Dasornis*, imperfectly known from the skull, which is considered to resemble the Dinornis of New Zealand. Fragmentary remains indicate the kingfisher *Halcyornis*, the vulture *Lithornis*, besides birds like the heron and sea-swallows. The albatross is represented by an allied genus, *Argillornis*, and *Odontopteryx* is a bird with some affinities to the duck tribe, which had long bony teeth on the jaw, which was probably covered with horn. A struthious bird referred to the genus *Macornis* is found in the Headon beds of the Isle of Wight, and some other birds are known from the Hempstead beds and the Bracklesham beds.

Evolution and Succession of Mammalia.—The oldest mammals are chiefly known from teeth. Molar teeth of *Microlestes*, from the Rhætic beds in this country, and Keuper beds of the Trias of Germany, are shown by the premolar teeth, named *Hypsiprymnopsis*, to so closely resemble *Plagiaulax* of the Purbeck beds, and the living kangaroo-rat Hypsiprymnus, that we may affirm descent without recognised modification of plan. Under the name *Neoplagiaulax*, Dr. Lemoine has described a near ally of Plagiaulax from the Lower Tertiary rocks. One of the most interesting of recent discoveries is the skull of the South African Triassic mammal, named by Sir Richard Owen *Tritylodon*, which has three longitudinal rows of cusps on the molars, closely resembling the *Triglyphus* of Fraas from the Trias of Stuttgart. Professor Cope has found a representative of the type in the Tertiary beds of North America, which is named *Polymastodon*.[3] The lower jaws of mammals from the Stonesfield slate, termed *Amphitherium* and *Phascolotherium*, with strong marsupial characters, combine many characters of the Insectivora, and are associated with a humerus and femur which indicate a generalised Insectivorous type, modified from a Monotreme stock in the direction of the marsupial plan.[4] The only mammal from

[1] Odontornithes: Extinct toothed birds of North America, by O. C. Marsh.

[2] "Recherches anatomiques et paléontologiques—l'histoire des oiseaux fossiles de la France." 4to. 1867–74.

[3] Cope: "The Tertiary Marsupialia," American Naturalist, July 1884.

[4] Q. J. G. S., August 1879.

Stonesfield with teeth of placental type is *Stereognathus*. The affinities of the numerous mammals from the Purbeck beds, *Spalacotherium, Triconodon, Galestes, Plagiaulax*, &c., are apparently marsupial.[1] There are

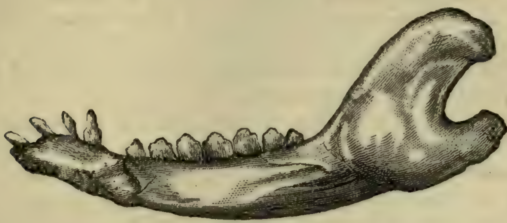


Fig. 147.—Phascolotherium. Lower jaw enlarged.

no herbivorous marsupials in the Tertiary rocks; and Professor Gaudry[2] urges that this group would be at a disadvantage in the struggle for existence, as compared with higher herbivorous mammals, from the way in which the movements of the parent are controlled by the helpless condition of the young, and that this disadvantage might have led to their extermination in the European Tertiary area. Carnivorous marsupials, which so closely resemble the existing opossums that it is not easy to separate them by generic characters, are found in the older Tertiaries of Paris, Auvergne, and Vaucluse. These Carnivorous marsupials of Insectivorous type are termed by Professor Cope Creodonta.[3] *Hyænodon* and *Pterodon*, somewhat intermediate between the placental and implacental types in their dentition, are inferred by Gaudry to have been marsupials from the form of the axis vertebra. Professor Huxley regards them as connecting the Carnivora and Insectivora. This intermediate character is found in other genera, such as *Palæonictes* and *Cynohænodon*, from the Phosphorites of Quercy. *Arctocyon* is an omnivorous mammal, resembling the marsupial bears. This blending of characters in Tertiary genera is intelligible on the hypothesis that implacental mammals of the Secondary period of geological time become ultimately developed into the insectivorous placental type; and in this way Professor Gaudry interprets the resemblances to marsupials seen in some fossil carnivora and in living lemurs.

There is no fossil evidence as to the parentage of Cetacea. *Palæocetus Sedgwicki*[4] is recorded as a fossil from the Secondary rocks on the evidence of its mineral condition, which is that of fossils from the Secondary clays. Zeuglodon occurs in the Barton clay, Squalodon in the Miocene rocks and crag, Balenoptera dates from the Headon beds;[5] Halitherium, from the Crag and Middle Tertiary, is intermediate between the Dugong and Lamantin; *Pugmeodon* is intermediate between the Lamantin and Halitherium.

[1] R. Owen: "Purbeck Mammalia:" Palæontographical Society.

[2] See Gaudry: "Enchainments du Monde Animal," one of the most important modern contributions to Palæontology, in which most of the following facts concerning mammals may be found.

[3] "American Naturalist," 1884.

[4] Geol. Mag., Feb. 1865, p. 54.

[5] Q. J. G. S., vol. xxxvii.

The Pachyderms form a large group, in which extinct fossil genera have marked resemblances to living species. Thus the *Rhinoceros* was preceded by *Acerotherium*, *Palæotherium*, and *Paloplotherium*, and differences are found in the form of the skull and the dentition. *Acerotherium* is essentially a *Rhinoceros* without horns, and consequently with smaller nasal bones. Fossil species of *Rhinoceros* show all intermediate conditions of this region of the skull. The American species of *Acerotherium* have three pairs of incisor teeth, as in *Palæotherium;* and this number is preserved in the extinct *Rhinoceros sivalensis* of India, though in other species the incisors become lost. Tapirs are traced back by the American genus *Hyrachyus* to *Lophiodon* in the Eocene. Pigs of the genus *Sus* appear in the Middle Miocene. *Sus Lockarti* is nearly allied to *Hyotherium*, and this genus is closely allied to *Palæochærus*, which resembles the peccary of South America. *Palæochærus* passes to *Chæropotamus*, and this genus is closely related to *Dichobune* of the Headon beds. Pachyderms are the prevalent type in the older Tertiaries of Europe.

The oldest known Ruminants are *Xiphodon*, *Dichodon*, and *Amphimeryx*. Most of the older American Ruminants possess, like *Xiphodon*, some characters of Pachyderms. This is exemplified by the French genera *Gelocus* and *Dremotherium*. All the chief ruminant types are found in the Upper Miocene. The older genera, such as *Oreodon*, are allied to *Anoplotherium*, and without horns. The first antelopes have the horns very small; and horns appear to have developed gradually, becoming relatively large in *Antelope recticornis* of the Lower Pliocene. The antlers of Ruminants also developed gradually in geological time, just as they grow in complexity during life in existing deer. In the Middle Miocene the genus *Dicroceras* has antlers with two prongs. In the Upper Miocene deer first appear in which the antler has three prongs; and it is only in Pliocene and Post-Tertiary deposits that antlers attain their full complexity, though since the extinction of types like *Cervus Sedgwicki* of the Forest Bed, and the *Cervus megaceros*, no greater development of antler has occurred. Since the older fossil antlers are always attached to the skull, they have been regarded as permanent appendages in those types. When they began to become deciduous, at first only the upper portion of the antler was shed, long pedestals remaining attached to the frontal bones. The portion shed gradually increased in length.

The earlier Ruminants, *Oreodon*, *Dichodon*, and *Xiphodon*, have canines and incisors in the upper jaw like Pachyderms. It is, however, impossible to discover from study of the teeth what the Pachyderm type was from which the Ruminants were evolved. In the digits of the limbs existing genera show types in which a transition may be traced from those with four metapodial bones to those in which there is but one; and similarly, by tracing the ancestral forms of specialised living genera, a like series of modifications is met with, until in the older genera the metapodial bones are all separated. The steps by which this evolution was brought about are, according to

Gaudry—(1.) The first, second, and fifth metatarsals and first cuneiform bone are carried backward; (2.) the posterior proximal part of the third metatarsal is enlarged to sustain the cuneiform; (3.) the first and second cuneiform elements of the tarsus, the second and fifth metatarsals, and the trapezius become very small; (4.) various elements of the metacarpus and metatarsus are blended.

The ancestry of the Horse offers some difficulties which impose caution, for one line of descent for the Old World horses is suggested by European specimens, while Professor Marsh has developed another line of descent for the horses of America. In Europe the horse is traced from *Paloplotherium* by way of *Pachynolyphus* to *Anchitherium*, which is allied by its teeth to *Palæotherium*, though its limbs approximate to the more slender forms of *Paloplotherium* and *Hipparion*, which last is little more than a horse with two small supplemental digits, one on each side of the hoof. Monstrosities of the living horse sometimes have a supplemental digit developed with small hoof, such as is found in the Miocene *Hipparion*: Professor Marsh has figured the eight-hoofed Cuban horse, in which there is one such supplemental digit on each foot. Such a horse as *Equus stenonis* of the Pliocene, in which the teeth closely approximate to *Hipparion*, is regarded as the immediate ancestor of the Old World horse. In the characters of the extremities of the limbs, *Acerotherium* of the Middle Miocene diverges considerably from the type of the existing horse, for it has three large nearly equal digits, with a small one on the outside. *Palæotherium* makes a nearer approximation, for it has three digits, of which the middle one is slightly the largest. In *Paloplotherium* the lateral digits and metapodial bones are much reduced in size; while in *Hipparion* the reduction is carried a stage further, and the middle digit is proportionately enlarged.

The American ancestors of the horse are of similar type to those which are known in Europe. *Eohippus* had four well-developed toes, and the rudiment of another on each forefoot, and three toes behind. It was no larger than a fox. It is found near the base of the Eocene, in beds which yield *Coryphodon*. A little higher up in the Eocene is the *Orohippus*, which was of similar size, but had four toes in front and three behind, the middle one being the stouter. At the top of the Eocene is a third equine animal, termed by Professor Marsh *Epihippus*. It differed from its predecessor more in its teeth than in the digits. At the base of the Miocene is the *Mesohippus*, which was about as large as a sheep. It had three well-developed toes, and the splint of another on each forefoot, and three toes behind. In newer beds the animal is termed *Miohippus*. It has the splint bone of the outer digit reduced to a short rudiment, and the middle digit is becoming relatively stout. It may be compared with the *Anchitherium*. In the Pliocene beds is a three-toed horse as large as a donkey, termed *Protohippus*, which may be compared with Hipparion, and, like its European representative, differs from the older horse ancestors in the wavy complexity of the tooth enamel. Newer still is a near ally of the modern horse termed *Pliohippus*, which has lost the lateral digits, and

is distinguished chiefly by the teeth from the true horses which occur fossil in the most recent beds.[1] This series renders it likely that closely allied genera may descend by parallel lines from a distant parent stock.

What Professors Huxley and Marsh have done for the evolution of the Perissodactyla by tracing the history of the horse, Professor Cope has attempted for the Artiodactyla in the history of camels. The oldest American representative of the group is *Poëbrotherium* of the Lower Miocene. This genus has four incisor teeth, and has the metapodial bones distinct throughout life. In *Protolabis* the upper incisor teeth also remain well marked. This genus is associated in the Upper Miocene with *Procamelus*, in which there is first a marked retardation in development of the first incisor which leads to its atrophy; and secondly, an acceleration of ossification, by which a canon bone is formed by the blending of the metapodial bones, though they long remain separate. A further step in the change is seen in *Pliauchenia*, in which the number of premolar teeth is reduced from four to three, and the first and second incisors are lost. In *Camelus* the premolars are further reduced to two, and in *Auchenia* to one, though even this type shows its affinity with *Poëbrotherium* by retaining a separate condition of the elements of the canon bone during a portion of fœtal life. Procamelus was about the size of a llama, with the head and muzzle more elongated, limbs more slender, and neck shorter.[2] The giraffes have similarly been traced by Lydekker back to the Sivatheres, in which a shortening of the neck is associated with the development of palmate horns.

Thus both Artiodactyla and Perissodactyla are traced back to simpler types of ungulata, and Gaudry urges that they result from the necessity that the foot, when applied to the ground, should support the pressure of the body evenly. In the Perissodactyla the fibula rests directly against the tibia, instead of articulating with the calcaneum, as in the Artiodactyla. This arises from the external digit becoming rather more slender than the internal digit, and leads to the articulation of the heel-bone or calcaneum with the cuboid-bone becoming smaller, and this causes an attenuation of the fourth digit; so that the whole weight of the animal is thrown on the astragalus, which is carried by the naviculare, which is itself carried by the third cuneiform bone, which supports the third or middle digit of the foot. Hence it would follow that the astragalus of the odd-hoofed mammals, which are flattened in foot, is modified from the type of the even-hoofed mammals, and this conclusion is supported by the other tarsal bones. Therefore, though the modern classification into Artiodactyla and Perissodactyla is valuable as an evidence of evolution, the classification becomes less marked as ungulates are traced back in geological time.

North and South America have yielded several extinct orders of Mammals defined by Owen, Marsh, and Cope.

[1] Marsh, Amer. Jour. Sci., vol. xvii. p. 497.

[2] Rep. U. S. Geog. Surveys West of 100th Merid., part ii. vol. iv., 1877.

Elephants, *Mastodon* and *Dinotherium*, which date from the Miocene period, have furnished no palæontological evidence of their parentage, and in many other groups the evidence is imperfect.

Edentates lived in Europe in the Eocene and Miocene periods, though, in America, they are only known from the newest deposits. *Macrotherium* was an enormous animal of the Middle Miocene, which had relatively small hind limbs, and claws drawn back towards the metacarpals, so as not to impede progression on the ground. It might have been a climber. *Ancylotherium*, from Pikermi, is intermediate between climbing and walking edentates. Rodents occur in the Headon and Bembridge beds; porcupines in the Upper Miocene of Greece; hares in the Pliocene of Auvergne; beavers in the Upper Miocene, and the extinct genera only differ from those now living in minor characters. Hedgehogs are found in the Miocene of Auvergne, moles in the same strata, in the Rhine, and at the foot of the Pyrenees. Shrews are also Miocene, *plesiosorex* being so generalised as to present some characteristics of a hedgehog.

The Carnivora are fully represented in a fossil state. *Pseudælurus* is a primitive cat, which commenced in the Upper Eocene phosphorites of France; and there is a regular succession of Felidæ through the Miocene and Pliocene periods, though the true cats are most numerous in the newest Tertiary. It is only in the *Smilodon* of Buenos Ayres that we have evidence that the claws become retractile. There may be some reason for thinking that carnivorous animals are descended from the herbivora, since bears most nearly resemble the pachyderms. The Miocene genus *Amphicyon* had the most striking characteristics of dogs, yet was plantigrade like a bear, was probably able to climb, and resembled bears in minor dental characters. The genus *Hyænarctos* has an inner row of denticles to the teeth, and thus is intermediate between bears and *Amphicyon*. In the same way *Cynodon*, from the phosphorites of Quercy, bridges over the gap between the civets and dogs. Hyænas are in like manner related to civets, *Ictytherium* being a modified civet with four digits like hyæna, and it produced similar coprolites; while *Hyænictis* is a modified hyæna, closely approaching *Ictytherium*. The martens of the Miocene period approach the civets, but not so closely as to break down the distinction between the two groups.

The oldest Lemur is *Cœnopithecus*, from the Eocene. Several lemurs from the Eocene of Quercy show affinities with the ungulata which suggest a common origin for lemurs and several Eocene pachyderms. So marked are these characters, that the lemurine genus *Adapis* has sometimes been arranged with the pachyderms, while the lemur *Aphelotherium* was formerly placed near to that group.

The earliest Apes present affinities with pachyderms, which are marked in the genus *Cebochœrus*, from the lignites from Debruge. Hyracotherium has some ape-like characters. The teeth of *Oreopithecus*, from the Miocene of Italy, show resemblances to the pachyderm *Chœropotamus*. True apes from the Middle Miocene include *Semnopithecus*, from the Siwalik Hills and Montpellier. *Mesopithecus*, from Pikermi,

appears to have been a walker rather than a climber, and intermediate between *Semnopithecus* and the Macaques. The anthropomorphous apes include *Pliopithecus* and *Dryopithecus*. The latter is of a very high type, but differs from man in many points, but especially in the large size of the canines in the males.

Professor Gaudry considers that the doctrine of evolution would justify us in regarding a European deposit as Eocene if the mammals were numerous but unlike those now living, and unassociated with true ruminants, solipeds, proboscidians, and apes. In the older Miocene we should expect to find living genera rare, marsupials disappearing, pachyderms passing into horses, and the incoming of true ruminants. In the newer Miocene marsupials would be lost; but ruminants, horses, whales, edentates, elephants, carnivora, and apes are represented by numerous individuals and many genera, some of which diverge from living forms. In the Pliocene period the genera are mostly still living, though the species are extinct.

Summary.—If we endeavour to summarise the conclusions which the succession of life on the earth indicates, the most important generalisation is no doubt the fact that the life now existing is substantially the same as life has been in all the past ages of time. The combination of the different groups of organisms is of like character, though the genera and species have varied. There is no trace of a beginning. There is evolution, but it is only the evolution of genera and of ordinal groups, and not of classes.

It is chiefly by means of extinct families and orders that strata are characterised, and the periods of past time separated from each other; but when we bear in mind what the circumstances are which are causing extinction at the present day, we may doubt whether a classification so made is the best possible. Its method is unphilosophical. At least of equal importance with the occurrence of extinct types is the first appearance as elements in a fauna of genera and orders which still survive; for both are connected with the changed distribution of land and water which time has developed. The first appearance of organisms as a characteristic feature in a fauna, would divide the strata differently from the extinct types, and would show how local are all the phenomena of the succession of life. Many groups of organisms which still survive appear plentifully in the Cretaceous rocks, so that a palæontological division might be drawn on the evidence of plants and fishes and many intermediate groups of organisms, which link the Lower Greensand with strata below, and the Gault with strata above. The Trias is sharply cut off from the Lias above, and from Permian rocks below. The Primary period is certainly divided into two by a gap in succession of species between the uppermost beds of the Silurian and the lower part of the Devonian, which is not less marked than the other great changes in life, such as divide the Secondary and Tertiary rocks, or the Trias and Lias.

The names Palæozoic, Mesozoic, and Cainozoic, therefore, do not represent completely palæontological facts, and the divisions which they indicate are artificial when studied in the light of the groups of

animals composing the several faunas. The Sponges give no indication of the larger divisions of time; the Foraminifera introduce their new types gradually, so that we look to the Carboniferous rocks, the Trias, and the Chalk as furnishing the majority of existing genera. Among corals the Alcyonarians are scantily developed, yet date back to the older Primary rocks. The Rugosa are chiefly, though not exclusively, of Primary age; the Sclerobasic corals are not known prior to the Tertiary period; and the Perforata, which are common corals at the present day, date from the Cambrian rocks; the Aporosa are more numerous in the newer rocks than in the Primary period. The sea-urchins would tend to unite Secondary and Tertiary rocks together, while some urchin types show a remarkable connection between the Cretaceous and Tertiary periods. The Crinoids are an asthenoid group most numerous in the Primary period; but otherwise have little value in stratigraphical classification. The living groups of Crustacea do not suggest any of the existing divisions of the strata, since the higher forms are chiefly known from the Lias, the Cambridge Greensand, and the London Clay. The Lamellibranchiata furnish many surviving types in the Primary rocks, especially the Carboniferous; others become known with the Trias, Lias, Neocomian, Cretaceous, and Lower and Middle Tertiary. The Gasteropods commence gradually, one or two with a formation, though they are most numerous in the Carboniferous, Lias, and Chalk, until the Lower Tertiary introduces the majority of living forms. Hence there are nine or ten great palæontological divisions of British strata.

Palæontology has often been regarded merely as the aid which a naturalist contributes to the work of the stratigraphical geologist.[1] But in addition to this work which it was at first called upon to perform, palæontology has a more important rôle in the future history of science, in demonstrating the steps in the evolution and succession of faunas; and on this basis its evidence must always be important in forming a useful geological classification of strata.[2] It also contributes important evidence of physical changes which took place in adjacent regions. But the physical and palæontological evidences rarely coincide; so that for some time to come Stratigraphical classifications should be made independently, first upon the evidences of the Physical History of a Region, and secondly upon its Succession of Life.

[1] Twenty-five years ago we began to give effect to a different view by arranging the collections in the Woodwardian Museum, in the University of Cambridge, in the local faunas in which they were collected, since it was thus possible to trace the migration of life step by step as it became diffused on the earth in consequence of physical changes. This aspect of palæontology was originally suggested by the study of Count Munster's and other palæontological collections in the Woodwardian Museum, and its importance has since been enforced by studies of many collections in different parts of Europe.

[2] It is many years since Mr. R. A. C. Godwin-Austen wrote—"The artificial scale of formations which still figures in elementary treatises, more particularly with respect to Secondary Geology, represents an order of superposition and lines of separation which are both untrue as well with respect to the mineral masses as the forms they contain, the result of too hasty generalisation of local phenomena;" but notwithstanding some improvements the criticism remains still just.

The two methods may eventually be united, but it can only be by discovering the physical conditions which limited, determined, and changed the mineral characters of the strata, and changed the distribution of fauna and flora in the area which the strata occupy.[1]

Conclusion.

There is but one safe road in geology, and that is practical familiarity with facts. If we have succeeded in our elementary task of unfolding the origin of strata, and stating the ways in which their origin is bound up with the origin of igneous rocks and the succession of life on the earth, we shall have failed altogether in our purpose if the reader has not step by step tested both exposition and theory by familiar acquaintance with Nature. Thus practical knowledge is readily gained as it is needed; and facts and ideas easily become the student's own when seen or interpreted by himself. There can now remain no need to indicate lines of further work to be followed, for the student's chief needs henceforth are hammer, handbag, and notebook in connection with the subject of this volume.

We may, however, mention a few authors of the earlier period of Geological Research, whose every work may be profitably read, for they may long influence the future development of geological science. In physical geology there has been no greater master of description than John Macculloch; and Sir Henry de la Beche, W. D. Conybeare, and Adam Sedwick, knew better what to observe than most men. In volcanic geology, every writing of George Poulett Scrope is worthy of study; and in the philosophy of igneous rocks, Henry Clifton Sorby is the pioneer of the modern methods of research. Robert Alfred Cloyne Godwin-Austen laid the foundation of philosophical work among the strata; and Edward Forbes has been the greatest teacher in palæontology. It is by familiarity with the whole life-work of such men as these, their associates, colleagues, pupils, and successors, that the student may hope to assimilate the methods of thought which they used so well, and aid in advancing the science. The days of apprenticeship in science have ended, but it is still possible to study carefully every writing of the Great Masters in the country which they have made classical.

No study will be more profitable than the examination of a classical district with the original exposition of its geological structure; or the study of a type of life with a description in which matured experience guides the use of facts which elucidate the fossil form. When the cliff-sections have been examined, and drawn, and measured, and the student returns from disentangling complicated inversion of mountain ranges, he turns from Nature to books, books of detail in which other observers record their impressions of similar phenomena, in countries which may be compared with the area of his studies. The "Journal of the Geological Society of London," the "Geological Magazine," and publications of the Geological Survey contain the more important contributions to British Geology which are made from year to year, but even more

[1] Annals and Mag. Nat. Hist., Dec. 1867.

essential for research are the Catalogue of the Library of the Geological Society, Ormerod's Index to the Publications of the Geological Society, the Royal Society's Catalogue of Scientific Papers, and the publications of the Palæontographical Society. The literature which bears on work thus discovered and assimilated, but not before Nature has been first read with unbiassed powers, we turn from books to Museums; and there see the formations divested of sediment, with their life in the cabinets as on the old sea-beds; and so journey on from one museum to another, from country to country, comparing rocks and faunas, until the fossil life becomes migratory like that of this existing world of ours, and the conditions of its existence and modification are seen.

Thus the mind becomes saturated with a conception of the order of Nature, from which it is found that in all ways the past contains within itself the interpretation of the existing world. By using this illumination which the geologist has to give, the studies of the geographer and the naturalist are divested of their isolated character, and take places in a kosmos. In earlier times it was necessary, as a preliminary, to show how the present order of Nature is analogous to that exhibited in the strata, and that work was well done by Hutton and Lyell; but such comparison is only a step in grouping facts, explains nothing but the processes of Nature, and leaves the sequence and method of her work unexplored. The existing natural history of the earth may render its past history intelligible, but it does not account for its Existence, its course of Evolution, or its Facts; these are the inheritance of the Geologist. The progress of Earth's history has been from the past to the present, and the function of the geologist is to demonstrate how the existing world perpetuates the past, and has been evolved from it in all ways. The great departments of geology have been surveyed already; but the fabric of geological science has yet to be constructed. Facts lie to hand in all parts of the earth, and need only to be organised and vitalised by law to become luminous with their history. As this process takes form it will become clearer that Geological history is an Evolution, in which deposition of strata, elaboration of igneous products and ore deposits, and succession and distribution of life, are mutually dependent phenomena, which exemplify the persistence and action of physical laws that govern the earth without variableness.

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